What lies ahead in the AGE OF COVID-19

Curbing the alarming RISE OF PARKINSON'S

Space-based telescopes see ALIEN ATMOSPHERES

AMERICAN Scientist

May–June 2020

www.americanscientist.org

Engineering Genes to End MALARIA

Mosquito DNA offers a new line of attack on the disease

SIGMA XI
THE SCIENTIFIC RESEARCH HONOR SOCIETY

VISIT…

LANZAROTE

Caliente.com

WEAR THE COLORS OF ITALY'S LEGENDARY REGATTA

Raffinato™
Italy

To show exquisite details, necklace shown is not exact size.

The Regata Storica started in 1489, when the beautiful Caterina Cornaro, wife of the King of Cyprus, renounced her Cypriot throne in favor of Venice. The people of Venice welcomed her with a parade of elaborately-decorated gondolas, in a rainbow of popping colors. Every year since, the spirit of 1489 is recaptured in those world-famous canals when the famous Regata is repeated.

Our *Cornaro Necklace* is the essence of Venice, with the revelry of the Regata channeled into one perfect piece of jewelry. The gorgeous colors recall the Regata itself, and the 59 beads of authentic Murano are the only thing as historic and uniquely Venice as those gondolas. Each necklace is handmade by the legendary Murano glassmakers, where the proud Venetian tradition has been passed down from generation to generation, dating back to before the city threw that first famous party for Caterina.

> ***"...businesses on the crowded little island [Murano] also produce high fashion jewelry found on runways and in exclusive social settings around the world".***
>
> — The New York Times

Thanks to the Regata, we've visited Venice often and made great contacts, which is how we found and negotiated the best possible price on the highest quality Murano available. Now's your chance to share in the spirit of this legendary event without needing to break out your passport.

Satisfaction guaranteed or your money back. Enjoy the gorgeous colors of the ***Cornaro Murano Necklace*** for 30 days. If it doesn't pass with flying colors, send it back for a full refund of the item price.

Limited Reserves. You could easily pay $300 or more for a Murano glass bead necklace, but at **$29**, this genuine handmade Murano won't last. Don't miss the boat!
CALL 1-888-444-5949 TODAY!

Cornaro Murano Necklace

Stunningly affordable at **$29** + S&P

- **Made in Italy**
- **Murano glass**
- **25" necklace with lobster clasp**
- **Gold-finished settings**

Call today. There's never been a better time to let your elegance shine. 1-888-444-5949

Offer Code: RFG260-02. You must use the offer code to get our special price.

Raffinato™ 14101 Southcross Drive W., Ste 155, Dept. RFG260-02, Burnsville, Minnesota 55337 www.raffinatoitaly.com

A collection of impeccable design & craftsmanship from Italy.

AMERICAN
Scientist

Volume 108 • Number 3 • May–June 2020

DEPARTMENTS

130 From the Editors

131 Letters to the Editors

134 Spotlight
What might happen to COVID-19 over time? • A clear view of cloudy sprays • Uncommon habits of common spiders • Q&A with a climate modeler • Briefings

144 Sightings
Channeling lasers

146 Perspective
Decoding light from distant worlds
Kevin Heng

150 Engineering
The hard hat
Henry Petroski

154 Arts Lab
Depicting a fragmented world
Julie Sperling

158 Technologue
Is there a better way to control room temperature?
Da Li, Carol Menassa, and Vineet Kamat

SCIENTISTS' NIGHTSTAND

184 Book Reviews
Mathematical mosaics • Using data to understand the world

FROM SIGMA XI

189 Sigma Xi Today
Keeping the public trust in science • Knowing when to speak out • Sigma Xi will showcase art and science collaborations • Resources that have helped women in STEM

FEATURE ARTICLES

Vasa promoter/regulatory sequence
Anopheles stephensi
Liston, 1901
162

162 Gene Editing and the War Against Malaria
Using CRISPR gene drives to breed fitter mosquitoes may prevent a devastating disease.
Ethan Bier and Elliott Sober

170 Naming the Universe
The quick thinking of internationally minded astronomers led by John Herschel avoided stamping the Solar System with petty European rivalries.
Stephen Case

176 The Rise of Parkinson's Disease
Many cases of this neurodegenerative disease are preventable, and we may now know how.
Ray Dorsey, Todd Sherer, Michael S. Okun, and Bastiaan R. Bloem

THE COVER

Malaria is a devastating disease transmitted from person to person by mosquitoes. It kills more than 400,000 people per year, more than half of those deaths being children 5 years old or younger. CRISPR (clustered regularly interspaced short palindromic repeats) is a new gene-editing technology that acts like a pair of molecular scissors: It is used to "cut and paste" DNA sequences to alter gene function. In "Gene Editing and the War Against Malaria" (pages 162–169), Ethan Bier and Elliott Sober describe how biologists can now alter genes in a malaria-transmitting mosquito population by engineering a CRISPR gene drive, which mimics a natural evolutionary process. With this tool, a new gene can be inserted into the genome so that the alteration is rapidly passed down to successive sexually reproducing generations. Two gene-drive strategies have been found feasible: The first drives a local malaria-transmitting population to extinction; the second renders mosquitoes unable to transmit malaria, which breaks the malaria transmission cycle. (Illustration by Barbara Aulicino.)

From the Editors

Social Distancing and Connection

At the time we are finishing this issue for publication, the global pandemic of COVID-19 has caused many of us to change our habits and to work together in an effort to stay apart and reduce transmission. The staff of *American Scientist* feel fortunate that we've been able to continue to work, and we know that many of the researchers among our readers are at the forefront of the efforts to confront this pandemic. We hope that the content in this issue helps to keep your mind active during social distancing. In addition, we encourage you to come together virtually and discuss any of the content of the issue with us and with other readers on our social media pages. We're always interested in your feedback, and right now all forms of virtual connection are helpful.

In this issue's *Spotlight* section, digital features editor and ecologist Katie L. Burke takes a direct look at COVID-19 (short for coronavirus disease 2019) and discusses with an epidemiologist what the future may hold for the novel coronavirus ("What Might Happen to COVID-19 Over Time?" on page 134).

Unfortunately, COVID-19 isn't the only transmissible disease that the world must worry about. Ethan Bier and Elliott Sober discuss ways that CRISPR gene editing might help combat the spread of malaria by making the mosquitoes themselves more resistant to spreading the parasite ("Gene Editing and the War Against Malaria," pages 162–169). Bier and Sober provide a solid backgrounder on the gene drives behind CRISPR and also take a close look at the ethics of organism modification.

Also in this issue, Ray Dorsey and his colleagues present an update about Parkinson's disease ("The Rise of Parkinson's Disease," pages 178–183). This neurological affliction is increasingly common, and the number of cases more than doubled between 1990 and 2015. Evidence points to preventable triggers for this disease, and the authors discuss what must be done to turn the tide.

Elsewhere in this issue, Julie Sperling, a mosaic artist with an environmental policy background, looks at ways that art can reengage those who feel disconnected from the human-induced changes to our world ("Depicting a Fragmented World," Arts Lab, pages 154–157).

We hope that the wide range of topics this issue allows you to dive deep and consider each one more closely, while also introducing you to research outside of your own areas of expertise. Although we may have to distance socially for the good of all, let's find ways to connect however we can.

—*Fenella Saunders* (@FenellaSaunders)

AMERICAN
Scientist
www.americanscientist.org

VOLUME 108, NUMBER 3

Editor-in-Chief Fenella Saunders
Managing Editor Stacey Lutkoski
Senior Consulting Editor Corey S. Powell
Digital Features Editor Katie L. Burke
Contributing Editors Sandra J. Ackerman, Deb Boxill, Emily Buehler, Charles Q. Choi, Christa Evans, Jeremy Hawkins, Jenny Jennings Foerst, Diana Robinson, Heather Saunders
Editorial Associate Mia Evans

Art Director Barbara J. Aulicino

SCIENTISTS' NIGHTSTAND
Book Review Editor Flora Taylor

AMERICAN SCIENTIST ONLINE
Digital Managing Editor Robert Frederick

Publisher Jamie L. Vernon

CIRCULATION AND MARKETING
NPS Media Group • Beth Ulman, account director

ADVERTISING SALES
advertising@amsci.org • 800-282-0444

EDITORIAL AND SUBSCRIPTION CORRESPONDENCE
American Scientist
P.O. Box 13975
Research Triangle Park, NC 27709
919-549-0097 • 919-549-0090 fax
editors@amscionline.org • subs@amsci.org

PUBLISHED BY SIGMA XI, THE SCIENTIFIC RESEARCH HONOR SOCIETY
President Geraldine L. Richmond
Treasurer David Baker
President-Elect Sonya T. Smith
Immediate Past President Joel R. Primack
Executive Director Jamie L. Vernon

American Scientist gratefully acknowledges support for "Engineering" through the Leroy Record Fund.

Sigma Xi, The Scientific Research Honor Society is a society of scientists and engineers, founded in 1886 to recognize scientific achievement. A diverse organization of members and chapters, the Society fosters interaction among science, technology, and society; encourages appreciation and support of original work in science and technology; and promotes ethics and excellence in scientific and engineering research.

Printed in USA

Litigating Pollution

To the Editors:

In their article “How Property Rights Can Fight Pollution” (March–April), Lawrence Cahoon, Robert Cutting, and Michael Mallin promote using individual actions to protect property rights as a way to address toxic chemical cross-boundary pollution. The authors do not provide a balanced discussion of the advantages and disadvantages of using nuisance law and property rights to address “invisible” pollution.

The authors accurately and succinctly describe the limitations and some failures of the government regulatory system, and then pivot to a court-based case-by-case system. Such a system would not have national health-protection standards, and there is little likelihood that a local or state decision could be effectively used as a precedent in other states or even in neighboring counties without spending substantial resources on experts, testing, and other court costs in each and every case. This burden would limit health protections to those with abundant financial resources, such as corporations and large landowners.

The flaw in the authors’ argument is that they appear to want to replace the regulatory system without discussing the corollary effects. Once we elevate individual property rights above societal concerns, the jurists could move to undo most national oversight of interstate commerce, civil rights, and national environmental and health regulations. The result of their approach is not a regulatory scheme for a world that is highly interconnected and has finite resources.

The federal regulatory record for the past 35 years is decidedly mixed, and there should be a discussion of its limitations as well as its substantial successes. I would argue that its failures arose, in large part, from being forced to become rigid by conservative and corporate legal challenges. The authors mention in passing the need in each nuisance case to have scientific evidence of damage, economic impacts, and personal injury. Experience has shown that these are difficult issues requiring a great deal of expertise and expense, and results in the courts have been mixed.

Focusing on the litigation of property rights would undo 70 years of environmental and regulatory laws that reflect the interrelationships of the economy, the environment, and health. The authors emphasize individual property rights over collective societal rights, but the larger implications for education, civil rights, protection of natural resources, and protection from global problems such as climate change need to be discussed.

Robert Ginsburg
Chicago, IL

Drs. Cahoon, Cutting, and Mallin respond:

Property rights exist concurrently with the statutes that create the regulatory agencies. A return to historic property rights will enhance the ability of the regulatory system to protect public health by requiring better data and more scientific analysis before release into the environment is authorized.

If property rights are enforced, regulatory agencies could easily adapt in several ways. They could condemn pollution rights and make polluters pay fair value for those rights (as an efficient market economy demands, economists agree), or they could impose emissions charges on polluters. The agencies could require testing before materials that otherwise escape review are released into other properties, or they could reduce emissions and discharges to zero, as the Clean Water Act purports to require. Given the tools of additional data and court backing, regulatory agencies should become more effective

American Scientist (ISSN 0003-0996) is published bimonthly by Sigma Xi, The Scientific Research Honor Society, P.O. Box 13975, Research Triangle Park, NC 27709 (919-549-0097). Newsstand single copy $5.95. Back issues $7.95 per copy for 1st class mailing. U.S. subscriptions: one year $30, two years $54, three years $80. Canadian subscriptions: one year $38; other foreign subscriptions: one year $46. U.S. institutional rate: $75; Canadian $83; other foreign $91. Copyright © 2020 by Sigma Xi, The Scientific Research Honor Society, Inc. All rights reserved. No part of this publication may be reproduced by any mechanical, photographic or electronic process, nor may it be stored in a retrieval system, transmitted or otherwise copied, except for onetime noncommercial, personal use, without written permission of the publisher. Second-class postage paid at Durham, NC, and additional mailing offices. Postmaster: Send change of address form 3579 to Sigma Xi, P.O. Box 13975, Research Triangle Park, NC 27709. Canadian publications mail agreement no. 40040263. Return undeliverable Canadian addresses to P. O. Box 503, RPO West Beaver Creek, Richmond Hill, Ontario L4B 4R6.

Discover Egypt
Nov 18 - Dec 1 2020!
Optional Extensions:
Abu Simbel - Nov 30
The Red Sea - Dec 1-5
$4,995 per person twin share + air

Argentina Eclipse
December 8-19, 2020
With Optional Pre-trips to Peru or Easter Island!
$5,995 per person twin share + air

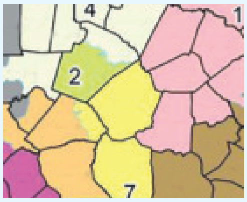
We invite you to travel the World with Sigma Xi!

SIGMA XI *Expeditions*
THE SCIENTIFIC RESEARCH HONOR SOCIETY
Phone: (800) 252-4910

For information please contact:
Betchart Expeditions Inc.
17050 Montebello Rd, Cupertino, CA 95014-5435
Email: SigmaXiInfo@betchartexpeditions.com

Online | @americanscientist.org

Health Economics Lessons from Coal Country
In both China and the United States, communities' economic and physical health are wedded to the coal industry, for better or for worse.
https://bit.ly/2TU2GCm



Detecting Gerrymandering
Rooting out biased voter districting is an active research field, but ending the practice takes more than mathematical know-how.
https://bit.ly/2TCbqgm

The Dangerous Resurgence in Race Science
Bret Stephens's recent *New York Times* column on "Jewish genius" is another example of how pseudoscientific claims about race and intelligence extend the history of eugenics into the present day.
https://bit.ly/2W1Adw8

Check out *AmSci Blogs*
http://www.amsci.org/blog/

Find *American Scientist* on Facebook
facebook.com/AmericanScientist

Follow us on Twitter
twitter.com/AmSciMag

Join us on LinkedIn
https://www.linkedin.com/company/american-scientist

Find us on Instagram
http://instagram.com/american_scientist/

Read *American Scientist* using the iPad app
Available through Apple's App Store

than the hamstrung political footballs many have become.

The individual lawsuits to which the letter-writer refers exist now, but the cases are laboring under a much more difficult subjective legal theory of nuisance. For instance, the Sabin Center for Climate Change Law has a database that contains references to thousands of cases that Justice Ruth Bader Ginsberg has noted on climate change alone—and there are thousands more untested pollutants.

Shifting back to trespass would reinstate an objective standard and require that sources pay for the privilege to pollute into other spaces. Sources would have to either secure consent, receive the government assist of condemnation for pollution easements, or seek other disposal or treatment options. Any of these options would enhance public health. That is why we offer property rights as a solution to several problems at once. Such rights would boost regulatory agencies by requiring adequate data and consideration of the science of the pollutants' effects on the rest of the population.

Tungsten's Mixed History

To the Editors:
I greatly enjoyed Ainissa Ramirez's informative article on the early history of tungsten filaments ("Tungsten's Brilliant, Hidden History," March–April). She ends her story with a quote from Thomas Edison in 1922.

Had she continued the story, she could have described the effect that demand for the previously obscure metal had on the world economy and on colonialism, as well as, incidentally, on world literature. The major deposits, as with many elements, were in the Bolivian and Peruvian Andes (although today China is the main source). The conditions in those mines led the Peruvian national poet, César Vallejo, to pen in 1931 his one true prose novel, *El tungsteno*. A work of social realism, it exposed the horrible conditions in foreign-owned tungsten mines.

Michael Geselowitz
Hoboken, NJ

To the Editors:
I read Ainissa Ramirez's article on William Coolidge with interest. Because I started my career at General Electric, his name is well known to me. The lore was that Coolidge once said that if he'd known anything about metallurgy when he started, he would have known that making ductile tungsten was impossible. This sentiment became the battle cry for projects at GE when people wanted to start projects that seemed impossible.

There was another famous fable around the invention of particularly durable plastic. The inventor had been failing in his efforts to create a hard, durable plastic formulation. One day, being lazy, he didn't clean up his lab mess and left a stir rod in a flask with his new test compound. The next day he was unable to remove the stir rod and had to break it out of the flask. There is a picture in the halls of GE's research and development center with the "lollipop" thus formed. That plastic became a very big product for GE

Bob Black

Chapel Hill, NC

Population and Climate

To the Editors:
I found Samantha Jo Fried's article on climate science interesting ("How Climate Science Could Lead to Action," January–February), but I did not see any mention of overpopulation as a cause of climate change. Does she think that overpopulation is a cause of climate change? If so, why was it not mentioned in the article?

John Alcock
Tempe, AZ

Dr. Fried responds:
Like Dr. Alcock, I believe that the Earth can't support an infinitely growing population of people, particularly with the toll our species takes on the environment. And I trust the experts who confirm that there is correlation, if not direct causation, here.

But because I argue that more data and information do not lead directly to action—and population data are not an exception to this belief—I must provide a mental model that might help us build local, national, and even international coalitions around environmental preservation.

This responsibility leads me to the question: How would we work on the problem of population growth together? We could tell folks to remain chaste forever, which I don't think would win hearts and minds. We can suggest that not everyone should have families, and we can champion birth control. However, we risk alienating people who have strong cultural or religious reasons for opposing birth control, or who believe that families are sacred.

Not to mention, plenty of rhetoric around population control already exists, and has existed for quite some time: It entered popular discourse in the mid-1940s, after World War II. This rhetoric is older than environmental rhetoric. For this reason, I would conclude (as I have with the data-to-action paradigm) that it's actually keeping us from building coalitions toward our goal of protecting the environment.

When it comes to discourse about population growth and the environment, we should also be wary of what we're saying about women's bodies and control thereof. Poor women, women of color, and women from the global south especially suffer at the hands of population control rhetorics. Such discourse can also negatively affect people with physical or mental illnesses. To me, at least, our urge to secure the environment derives from an urge to protect one another. If we're not doing that, what are we fighting for?

This question about population control is meaningful to me, and it helped me come to this conclusion: Because we are fighting for and with one another, environmental coalition-building is rooted in the question of what we owe to one another, and to the place that gives us the opportunity to owe things to one another in the first place.

I worry that pointing out folks' irrationality about climate—that is, clarifying the difference between climate and weather, or explaining collective carbon footprints—will backfire as a strategy. As you suggest, the information is out there, but some people are actively choosing not to invest in that knowledge. If we really believe that a path to change involves more widespread investment in scientific ways of knowing, then it's our duty to listen to people who don't trust climate science. It's our responsibility to figure out what life experiences they've had, why alternative information is more appealing to them, and what we can do to gain their trust.

It's also a reality that we can't win over everyone, and that we need to cast a wider net in our rhetoric about climate change, one that goes beyond trying to sway the most stubborn. An even more winning strategy, then, involves having conversations with people who are ambivalent, or who understand the existential threat but don't yet know what to do about it (and most of us fall into this category). If we really believe that a path to change involves more widespread investment in acting on these scientific ways of knowing, then it's our duty to have conversations about conservation as a social movement, and not just to offer information that someone can either believe in or reject.

Household Inferences

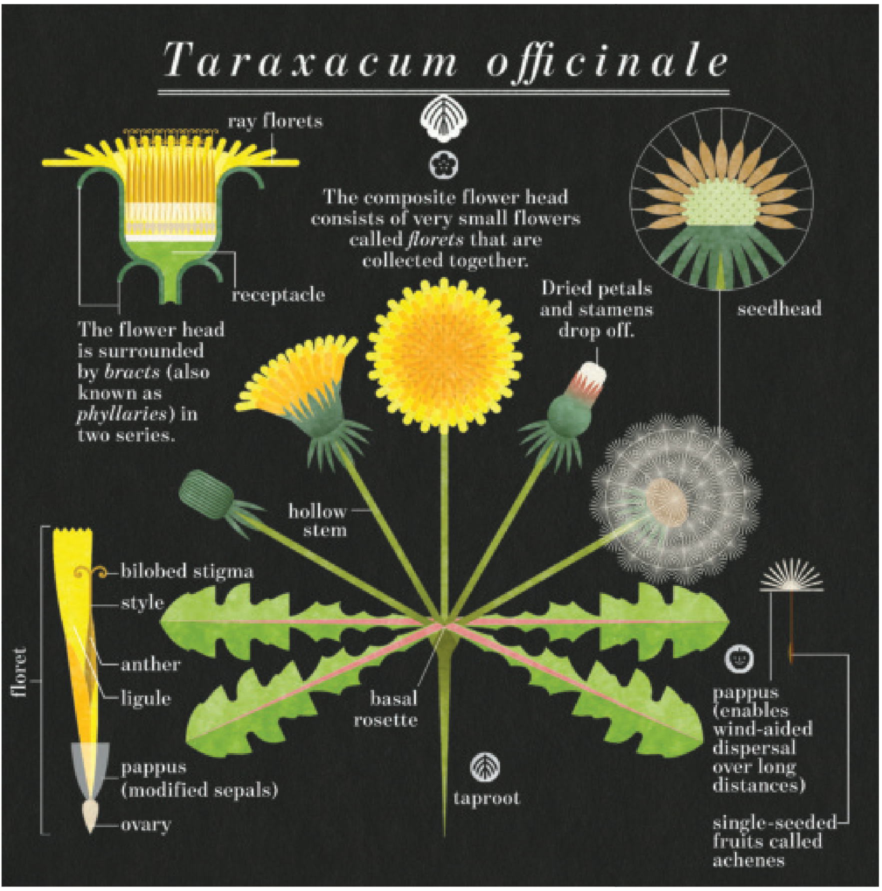
To the Editors:
Many thanks for Henry Petroski's seemingly mundane article on failure analysis ("Solving Failures Around the House," January–February), which I contemplated when our dishwasher would not drain. Surely it was a failed controller, or something with the drain pump? It was neither, and in solving the mystery I realized how related this detective work is to successful scientific inquiry. We form hypotheses about nature and eliminate them by testing assumptions or corollaries; this process is most efficient if we can eliminate groups of similar hypotheses using the "strong inference" approach that the late biophysicist John R. Platt wrote about in *Science* in 1964. Often the best answer comes from an unexpected direction, calling for an open mind and that mysterious (often unconscious) creative process Petroski refers to as "a good guess."

Nickolas M. Waser
Tucson, AZ

How to Write to *American Scientist*

Brief letters commenting on articles appearing in the magazine are welcomed. The editors reserve the right to edit submissions. Please include an email address if possible. Address: Letters to the Editors, P.O. Box 13975, Research Triangle Park, NC 27709 or editors@amscionline.org.

Botany Corner


Taraxacum officinale
ray florets
The composite flower head consists of very small flowers called *florets* that are collected together.
receptacle
Dried petals and stamens drop off.
seedhead
The flower head is surrounded by *bracts* (also known as *phyllaries*) in two series.
hollow stem
floret
bilobed stigma
style
anther
ligule
pappus (modified sepals)
ovary
basal rosette
taproot
pappus (enables wind-aided dispersal over long distances)
single-seeded fruits called achenes

Kaija Saaremäel

What Might Happen to COVID-19 Over Time?

The novel coronavirus is unlikely to go away completely after its first outbreak. People are only beginning to grapple with what comes next.

To deal with the global pandemic of a novel coronavirus, people all over the world have scrambled to enact social distancing so as to reduce the speed with which the virus is spreading—key to reducing the strain on health care systems. But even as different countries have met that threat with varying degrees of success, they need to prepare for the aftermath. There is a real possibility that this outbreak is not the last COVID-19 curve we'll need to flatten.

Epidemiologist Stephen Kissler of Harvard University and his coauthors published a paper in *Science* on April 14 that explores potential scenarios. "There's a good chance that we'll see some further waves of infection following this first one," he says. Two crucial variables will affect the timing and number of resurgences: how well the virus is transmitted during warmer months, and how long immunity lasts in people who have recovered from the viral infection.

"It's unlikely that the outbreak will just die out over the summer, as some have suggested," Kissler says. His team's study indicates that *severe acute respiratory syndrome coronavirus 2* (SARS-CoV-2, the virus causing coronavirus disease 2019, or COVID-19) can spread at any time of year because there are so many susceptible people. However, if the virus becomes less transmissible over the summer months—which has been the case for some other coronaviruses and the flu—that could help reduce the rate of infection. For ongoing or emerging outbreaks, delaying the spread as the weather warms will be a boon.

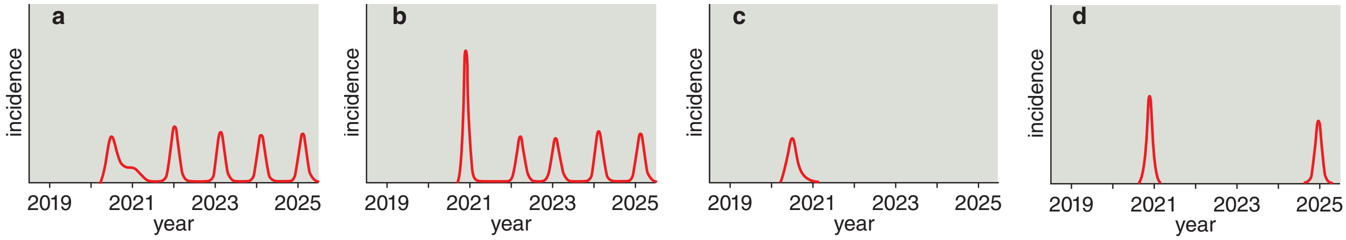
How long immunity lasts will strongly affect when we might see a resurgence in infections—from months to years after the end of the current surge. If immunity is short-lived, as is the case for seasonal flu and colds caused by other coronaviruses, then there could be another wave of SARS-CoV-2 infection in the fall. The previous influenza pandemic—the swine flu H1N1 in 2009—had a second wave of infection after a winter-spring outbreak, Kissler points out. "There was still transmission over the summer, but it was lower. Then we saw a resurgence in the autumn," he explains. Regarding SARS-CoV-2, he says, "We may have to do these social distancing measures again in the fall as the transmissibility rises again."

If immunity lasts years, as was the case for the SARS-CoV-1 outbreak in 2003, or if there is some cross-immunity between this novel virus and other related coronaviruses already circulating within the general population, then it could be two or more years before a resurgence occurs. By then, there may be effective treatments or vaccines in place. In general, though, immunity tends to last longer when viruses incite a stronger immune response. Considering that people can have SARS-CoV-2 without symptoms, the extended-immunity scenario seems unlikely.

Kissler and his coauthors show that if immunity to SARS-CoV-2 is not permanent, it will probably enter into regular circulation among humans. That could mean people will need to deal with one or more resurgences over the next year, or that this disease could become another seasonal disease like the flu and various common colds.

Epidemiologists, including Kissler and his team, are actively studying the length of immunity to and the seasonality of SARS-CoV-2. The progression of COVID-19 infections over the summer will reveal the virus's seasonality. Epidemiologists will need more time to determine how quickly immunity wanes. "We're still months to even a year away from knowing for sure how the immunity is going to look," Kissler says. In the meantime, epidemiologists will monitor viral outbreaks, to home in on remaining chains of transmission of SARS-CoV-2. Deciding where to implement testing for infection continues to be a pressing issue.

"These outbreaks can spread so explosively," Kissler notes. That's why social distancing has been important, and will continue to be so in any upcoming outbreaks. In the longer term, we will need to constantly adjust to new information and prepare to change our behavior permanently. "This virus may be with us for a very long time," Kissler says, "and we need to think about what we can do to structure our own lives and even our society for the reality of this and of whatever other outbreaks come our way in the future."—*Katie L. Burke*



Modeled scenarios of novel coronavirus outbreaks suggest the possibility of resurgence. The selected scenarios are (*a*) no cross-immunity with other coronaviruses, 40-week immunity to SARS-CoV-2, and establishment of sustained transmission in late March; (*b*) no cross-immunity, 40-week immunity, and establishment in early September; (*c*) no cross-immunity, permanent immunity, and establishment in late March; and (*d*) some cross-immunity, two-year immunity, and establishment in mid-August. (Adapted from Kissler, S. M., et al. 2020.)

Urgent: Special Summer Driving Notice

To some, sunglasses are a fashion accessory…

But When Driving, These Sunglasses May Save Your Life!

Studies by the National Highway Traffic Safety Administration (NHTSA) show that most (74%) of the crashes occurred on clear, sunny days

Navigator™ Black Stainless Steel Sunglasses

Drivers' Alert: Driving can expose you to more dangerous glare than any sunny day at the beach can… do you know how to protect yourself?

The sun rises and sets at peak travel periods, during the early morning and afternoon rush hours and many drivers find themselves temporarily blinded while driving directly into the glare of the sun. Deadly accidents are regularly caused by such blinding glare with danger arising from reflected light off another vehicle, the pavement, or even from waxed and oily windshields that can make matters worse. Early morning dew can exacerbate this situation. Yet, motorists struggle on despite being blinded by the sun's glare that can cause countless accidents every year.

Not all sunglasses are created equal. Protecting your eyes is serious business. With all the fancy fashion frames out there it can be easy to overlook what really matters—the lenses. So we did our research and looked to the very best in optic innovation and technology.

Sometimes it does take a rocket scientist. A NASA rocket scientist. Some ordinary sunglasses can obscure your vision by exposing your eyes to harmful UV rays, blue light, and reflective glare. They can also darken useful vision-enhancing light. But now, independent research conducted by scientists from NASA's Jet Propulsion Laboratory has brought forth ground-breaking technology to help protect human eyesight from the harmful effects of solar radiation light. This superior lens technology was first discovered when NASA scientists looked to nature for a means to superior eye protection—specifically, by studying the eyes of eagles, known for their extreme visual acuity. This discovery resulted in what is now known as Eagle Eyes®.

Eagle Eyes® Lens
simulation

Slip on a pair of Eagle Eyes® and everything instantly appears more vivid and sharp. You'll immediately notice that your eyes are more comfortable and relaxed and you'll feel no need to squint. The scientifically designed sunglasses are not just fashion accessories—they are necessary to protect your eyes from those harmful rays produced by the sun during peak driving times.

The Only Sunglass Technology Certified by the Space Foundation for UV and Blue-Light Eye Protection. Eagle Eyes® features the most advanced eye protection technology ever created. The TriLenium® Lens Technology offers triple-filter polarization to block 99.9% UVA and UVB—plus the added benefit of blue-light eye protection. Eagle Eyes® is the only optic technology that has earned official recognition from the Space Certification Program for this remarkable technology. Now, that's proven science-based protection.

The finest optics: And buy one, get one FREE! Eagle Eyes® has the highest customer satisfaction of any item in our 20 year history. We are so excited for you to try the Eagle Eyes® breakthrough technology that we will give you a **second pair of Eagle Eyes® Navigator™ Sunglasses FREE—a $59.95 value!**

That's two pairs to protect your eyes with the best technology available for less than the price of one pair of traditional sunglasses. You get a pair of Navigators with stainless steel black frames and the other with stainless steel gold, plus one hard zipper case and one micro-fiber drawstring cleaning pouch are included. Keep one pair in your pocket and one in your car.

Your satisfaction is 100% guaranteed. If you are not astounded with the Eagle Eyes® technology, enjoying clearer, sharper and more glare-free vision, simply return one pair within 30 days for a full refund of the purchase price. The other pair is yours to keep. No one else has such confidence in their optic technology. Don't leave your eyes in the hands of fashion designers, entrust them to the best scientific minds on earth. Wear your Eagle Eyes® **Navigators** with absolute confidence, knowing your eyes are protected with technology that was born in space for the human race.

Receive the Navigator™ Gold Sunglasses (*a $59.95 value*) **FREE! just for trying the Navigator™ Black**

Navigator™ Gold Stainless Steel Sunglasses

Certified EAGLE EYES® was developed from original NASA Optic technology and was recently inducted into the Space Foundation Technology Hall of Fame.

Fit-ons available for $39 +S&H
Black or Tortoise-Shell design

Two Pairs of Eagle Eyes® Navigator™ Sunglasses ~~$119.90~~†

Offer Code Price **$49** + S&P **Save $70.90**

Offer includes one pair each Navigator™ Black and Navigator™ Gold Sunglasses

1-800-333-2045

Your Insider Offer Code: EEN889-06
You must use this insider offer code to get our special price.

Stauer®

14101 Southcross Drive W.,
Ste 155, Dept. EEN889-06
Burnsville, Minnesota 55337
www.stauer.com

Rating of **A+**

† Special price only for customers using the offer code versus the price on Stauer.com without your offer code.

Smart Luxuries—Surprising Prices™

A Clear View of Cloudy Sprays

Lasers and x-rays combined can capture quick-changing droplets as they break apart and evaporate.

Most cars still have internal combustion engines, and these engines work by spraying puffs of fuel into cylinders hundreds of times every minute—fuel that, when ignited, generates the explosions that move pistons and allow people to drive all across the planet. A critical part of the process is that the injected fuel must be vaporized fully prior to ignition; the presence of any liquid droplets leads to inefficient combustion and polluting soot. Scientists therefore would like to observe the fine details of how droplets break apart and evaporate. But more than a century after the invention of the automobile, peering deeply into that process remains challenging.

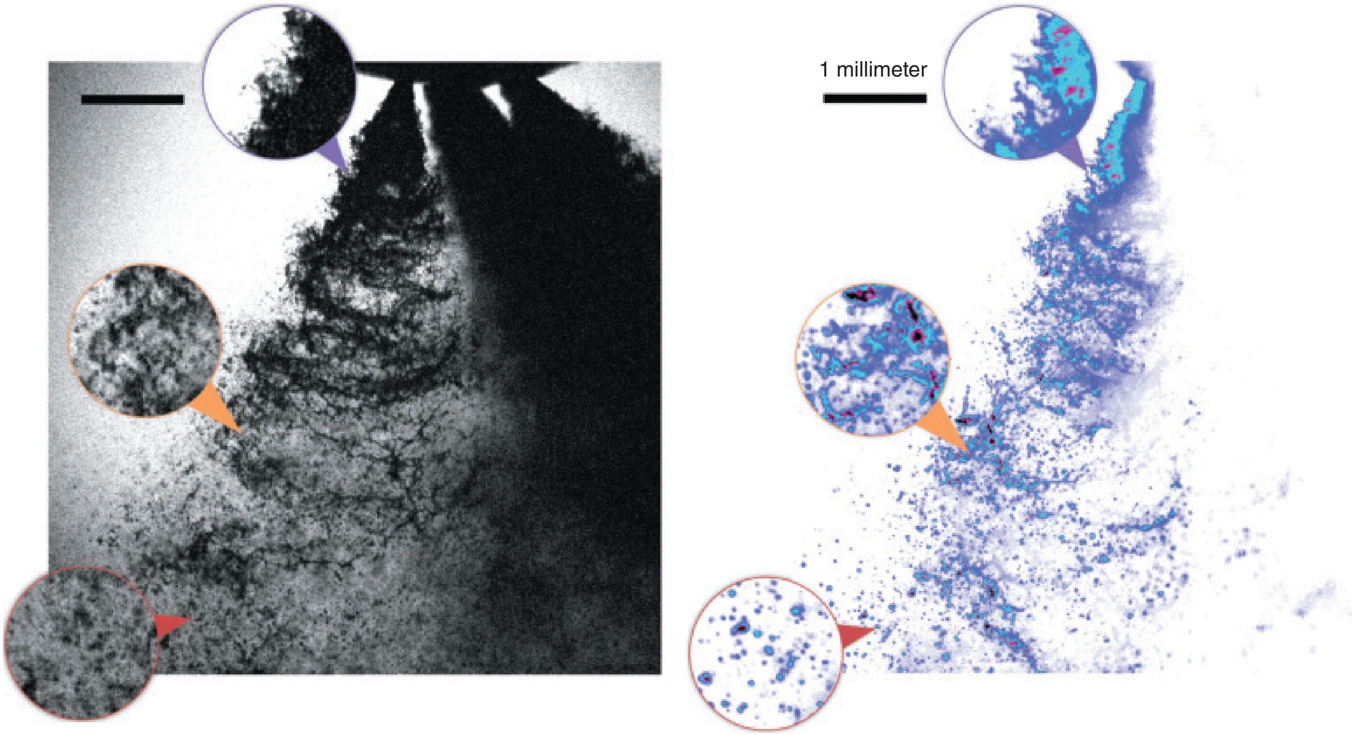
"You could think of trying to image a plane behind a cloud in the sky. In most cases, the plane is not even visible," says Edouard Berrocal, a physicist at Lund University in Sweden.

Now Berrocal and his colleagues have married two competing imaging techniques into one method that illuminates these sprays; it uses a combination of x-rays and near-infrared laser light to provide unprecedented views of droplet cloud structures. Their research, detailed in the February 20 issue of the journal *Optica*, may help lead to improved atomizing sprays for more efficient, less polluting fuel combustion. It could also benefit numerous other industrial applications, such as the sprayed droplets that are typically used for making the powders in pharmaceutical pills.

Most broadly, the new technique could allow researchers to see which theoretical models best describe spray behavior. Current models are limited by the blurry views that scientists have of the interior of a droplet cloud. New imaging techniques that suppress this blur could allow scientists to design spray systems based on empirically validated predictive models, rather than relying on a mix of limited modeling and laborious trial-and-error design, as is often currently the case, says Berrocal.

Sprays are difficult to image partly because of their complexity; thousands of microscopic droplets are involved. The behavior of those drops then must be recorded in less than a millionth of a second to capture physical changes that might prove critical to understanding spray behavior, such as whether and how larger drops fragment into smaller ones. In the past, most attempts at imaging sprays illuminated them with visible light, but studies show that the droplets scatter anywhere from 86 percent to more than 99 percent of the light beam in all directions. Such optical strategies therefore often lead to blurry or completely obscured images of the interior of the spray.

The black and white image (*left*) shows the results of a conventional technique for spray imaging known as *shadowgraph* imaging, in which a camera captures light transmitted through a spray, obtaining a silhouette. This technique can image the contours of the spray, but not the interior. The color image (*right*) uses *two-photon fluorescence imaging*. This new method produces less light scattering, resulting in a sharper image.



E. Berrocal et al.

One alternative imaging technique uses powerful x-rays, which droplets typically absorb, to create a silhouette of a spray. By analyzing the shadows the droplets make against a bright x-ray source, researchers can measure their density, which for instance can show how gasoline droplets are distributed within a spray, and in turn predict how the gasoline will burn. However, use of this strategy is limited because it usually requires large particle accelerators called *synchrotrons* to generate the intense x-rays.

Now Berrocal and his colleagues have developed a hybrid strategy that incorporates new versions of both optical and x-ray imaging methods to overcome some of those shortcomings.

The researchers' technique first generates x-rays from a compact, tabletop laser-plasma accelerator developed by physicist Olle Lundh on the Lund team. Although this device is much smaller than a synchrotron, it can generate bright beams of x-rays with energies between 1 and 10 kiloelectronvolts, which is in the right range for 100-micron-wide droplets to absorb.

The device fires rapid, near-infrared laser pulses, each lasting just 38 femtoseconds (or 38 quadrillionths of a second), into a pocket of helium gas. The pulses generate a plasma, a cloud of electrically charged particles. This process, Lundh says, "can support electric fields 10,000 times stronger than in conventional techniques using synchrotrons, reducing the amount of distance we need to accelerate particles to the high energies needed to emit x-rays." The resulting beam of x-rays is also relatively wide, large enough to image an area of spray that measures 20 by 20 millimeters. In comparison, synchrotron x-ray imaging of sprays covers areas measuring just 4 by 4 millimeters.

In parallel, the researchers use the same femtosecond laser pulses to perform an optical imaging technique called *two-photon fluorescence imaging,* which uses dye molecules that fluoresce only when they are illuminated by two photons at the same time. A camera is trained on the illuminated patch, tuned to the exact frequency of light that the dye molecules emit. The tightly focused, organized photons from the laser beam are likely to hit the dye in pairs, causing it to light up, if they hit it directly. Any photons that scatter, on the other hand, are unlikely to strike in synchronized pairs. As a result, scattered light doesn't contribute to the fluorescent glow, making it possible to filter out much of the blurriness that scattering normally causes.

Berrocal and his colleagues have begun testing their imaging system using jets of water created by a commercially available automotive fuel injector. (They started with water because experimenting with fuels requires more safety precautions.) The optical portion of their system was able to measure droplet size, shape, and position in great detail, and the simultaneous x-ray imaging helped determine droplet masses. The ultrafast x-rays and laser pulses combined to create what was essentially a stop-motion effect, freezing the motion of the droplets for clearer imaging. The joint strategy was sensitive enough to measure water droplets roughly 5 micrometers wide, about one-fifth the size limit for synchrotron x-ray imaging, and produced a level of clarity beyond that which conventional optical imaging of droplets can achieve.

"There has been this competition with advanced optical techniques on one side and x-ray imaging on the other when it comes to sprays. It's really nice to have a tool that can combine the two worlds into one," Berrocal says. "By combining advanced techniques in the visible and x-ray regimes, highly complementary spray information can be obtained in a way that has never been achieved before."

The researchers are currently expanding their technique to capture three-dimensional images of sprays. The next step would then be to boost the rate at which they can generate pulses. Right now they can produce one image every 10 seconds; their goal is one image per second, which would help scientists analyze how sprays evolve over time, Berrocal explains. He is also exploring the use of heat-sensitive dyes that would tell researchers the temperatures within the liquid droplets, another important factor in efficient combustion.

Taken together, these data could lead to cleaner-running cars and trucks, drugs that break down in the body at a more predictable rate, and improvements in many other industrial applications. The new imaging approach could also streamline testing. "The information we could provide modelers on how liquid is distributed everywhere in sprays could help provide evidence to validate which models of sprays work," says physicist Diego Guénot, another member of the Lund research team, "so that moving forward, the models can become predictive." —*Charles Q. Choi*

"WHAT'S WRONG, SCOTTY? ACCORDING TO YOUR DNA, YOU SHOULD BE HITTING .324."

Infographic | Eleanor Spicer Rice and Neil McCoy

The Uncommon Habits of Our Most Common Spiders

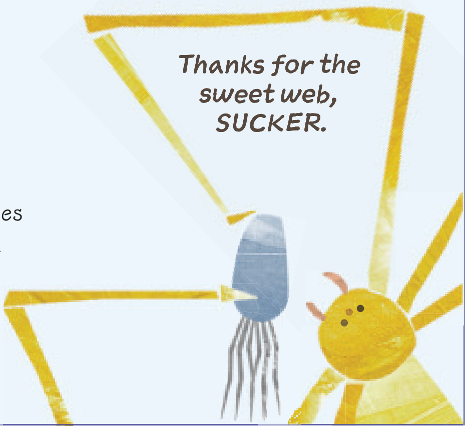
Whether you know it or not, odds are a spider is within reach. Wherever you are.

Like, right now.

Lucky you! These lovable weirdos do lots of excellent work all around us (thanks for the free pest control). But outside regular working hours, some species have odd personal lives. Here are five strange habits of some of the most common spider species creeping around homes and lawns across much of North America.

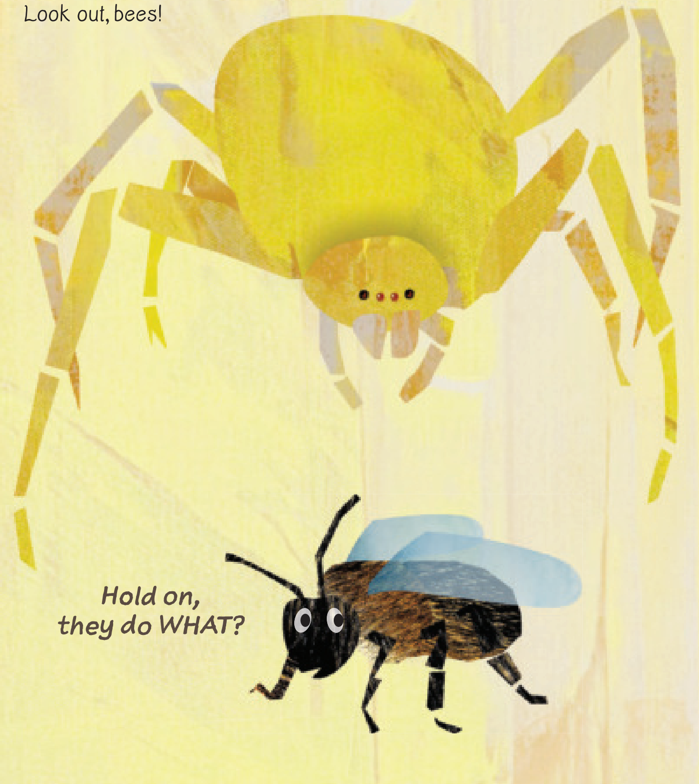
Cellar spiders (*Pholcus phalangioides*) steal other spiders' webs.

They trick victims by doing a "death dance," shaking webs like entangled prey. When the hungry web owner comes for a bite, the cellar spider tosses silk on it and eats it. Then she lives in the stolen web, eating captured creatures meant for the dead spider.


Thanks for the sweet web, SUCKER.

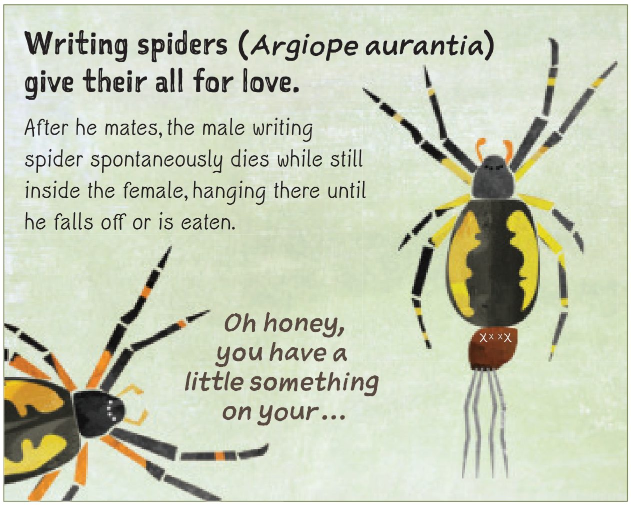
Goldenrod spiders (*Misumena vatia*) change colors.

To blend in with the flowers that they call home, these chameleons of the spider world have special cells that contain pigment that the spiders can selectively display until they perfectly match the flower. Look out, bees!


Hold on, they do WHAT?

Writing spiders (*Argiope aurantia*) give their all for love.

After he mates, the male writing spider spontaneously dies while still inside the female, hanging there until he falls off or is eaten.


Oh honey, you have a little something on your…

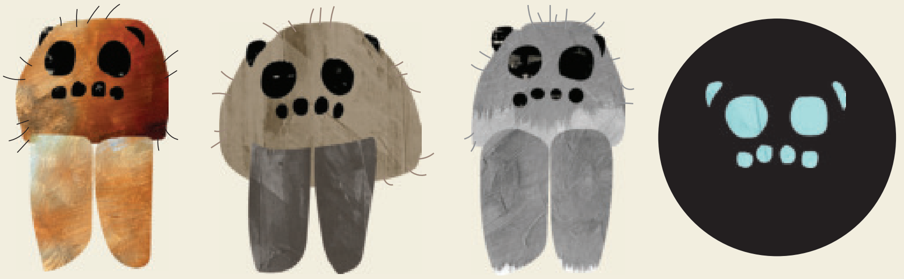
Grass spiders (*Agelenopsis* species) have questionable dating habits.

To avoid getting eaten while mating, male grass spiders in the mood release a chemical that causes their mates to go comatose until the deed is done. Then he's long gone, shorty.

Sigh… How am I ever going to meet my soul mate?

Wolf spiders (*Lycosidae*) are pretty much everywhere.

With nearly 2,400 species worldwide and more than 200 species in North America alone, wolf spiders come in many colors for blending in. Also, their eyes shine if you hunt for them at night with a flashlight.



© 2019 Ruthie Hauge Photography/www.ruthiehauge.com

First Person: Ben Santer

Atmospheric scientist Ben Santer is internationally recognized for his contributions to climate science, including the historic conclusion of the Intergovernmental Panel on Climate Change report in 1995 of the "discernible human influence on global climate." His research at Lawrence Livermore National Laboratory focuses on evaluating climate models, using statistical methods in climate science, and identifying "fingerprints"—both natural and anthropogenic—in observed climate records. He is the recipient of the 2019 Sigma Xi William Procter Prize for Scientific Achievement, *which has been annually awarded since 1950, with past recipients including conservation biologist Stuart Pimm, nuclear chemist Darleane C. Hoffman, and paleontologist Stephen Jay Gould.* American Scientist*'s Robert Frederick spoke with Santer about the current state of climate modeling, ongoing challenges, and what he finds encouraging.*

To what extent has climate modeling changed in the past few years?

Overall, we now have much more complex models of the Earth's system than we had when I started off in this field 35 years ago. Back then, we had relatively simple models of the atmospheric general circulation including very simple models of the upper surface of the ocean, which was essentially treated like a swamp. There was very little representation of the complexity of the full ocean general circulation and how the ocean interacts with the atmosphere. Now, we have these models that capture not only the three-dimensional circulation of the atmosphere, the oceans, and their interactions, but also sea ice, carbon cycles, ocean biogeochemistry, and atmospheric chemistry. In the next assessment reports of the Intergovernmental Panel on Climate Change, we'll even have three-dimensional ice sheet models: Think the Greenland ice sheet and the Antarctic ice sheets, and the interactions between those ice sheets and a warming climate and a rising sea level.

These new Earth system models are amazing tools for trying to understand the complexity of the real-world climate system, particularly these interaction terms—between what we're doing to the climate system by burning fossil fuels, increasing heat-trapping greenhouse gas concentrations in the atmosphere, warming, and increasing sea level, for example. So how is increasing the sea level, say, affecting ice shelves that are floating and holding back some of the Antarctic land ice that would otherwise be free to flow into the southern oceans and raise sea level further? We can study those kinds of interaction terms now with these Earth system models that have integrated ice sheets in a way we could not previously. That is huge, because arguably one of the biggest impacts of human-caused climate change is going to be felt through sea-level rise. We urgently need to better understand ice sheets on the move and—as we warm the planet's climate and start melting these big ice sheets—how rapid and how large their contributions to global mean sea level will be. That's a big uncertainty and something we urgently need to understand. We have a better shot at understanding that now with these integrated three-dimensional ice sheet models in full climate models.

Overall, it sounds like there's somewhat of a computing—or even a big data—problem.

Absolutely, because these complex models of the Earth system generate enormous volumes of data. For the next assessment report of the Intergovernmental Panel on Climate Change—the sixth assessment that is due out in a couple of years from now—we're looking at petabytes of simulation output. That's providing scientists around the world with information about every aspect of the climate system they might care to analyze. How do you extract meaning from those enormous data sets? How do you boil them down into some parsimonious set of patterns and time series that capture most of the information in the data set and that tell you about some of these interactions between atmosphere, ocean, carbon cycle, and ice sheets? How do you do that? Clearly, this is not just the domain of climate scientists, but also the domain of statisticians and mathematicians and computer scientists, who are very comfortable in this world of enormous volumes of data and extracting meaning from very large data sets. That's one of the reasons I'm fortunate to work at Livermore. We have excellent computational support and we, as climate scientists, routinely collaborate with folks who are trained as computer scientists.

In all of this, what encourages you?

About climate modeling, or about the future of humanity? [laughs]

How about "the future of humanity"?

Over my scientific career, I've witnessed the emergence of some human-caused warming signal from the background noise of natural climate variability. That was controversial nearly 25 years ago at the time of the finding of the second report of the Intergovernmental Panel on Climate Change, in 1995, that "the balance of evidence suggests a discernible human influence on global climate." But now it's incontrovertible that humans have changed the chemical composition of the atmosphere—by burning fossil fuels, primarily—and that those human-caused changes in chemical composition of the atmosphere have changed our planet's climate. Back then, one of the points of criticism—justifiable criticism of the discernible human influence finding—was "You folks are looking only at surface temperature, at surface thermometer measurements of the Earth's land and ocean temperature. If there really is a human-caused climate change signal lurking in observations, prove it to us. Look not just at temperature, but go beyond temperature. Look at the amount of moisture in the atmosphere. Look at the extent of snow and ice. Look at circulation patterns. Look at many other things: clouds, continental-scale runoff, snow pack, extreme heat, the properties of extreme events, intensity, frequency, duration. Convince us that this signal is not limited to surface temperature alone." And that's what's happened in the intervening years since the "balance of evidence" finding in 1995.

Climate scientists have examined literally dozens of different aspects of climate change, using a wide variety of different measurement systems and platforms: Think space, think ground-based, think LIDAR [light detection and ranging], think weather balloons, think these beautiful Argo [robotic] floats that are dropped into the ocean and then go down to 2,000 meters and phone home when they get back to the surface with their temperature and salinity measurements. All of this stuff shows that there's a signal, and that humans are largely responsible for that warming signal in the climate system.

So it's that scientific confirmation that is encouraging?

The thing that makes me optimistic is that, in tandem with that scientific understanding of the reality of the human-caused signal in the climate system, we've moved on in the public arena. The public debate today here in the United States seems to be not "Is there a warming signal, are humans affecting the climate?" but more, "What do we do about it, and how do we respond, and what sort of economic and political options do we have to address this problem?" Voices arguing that nothing is happening, I would say, have little credibility in today's world, given this overwhelming evidence to the contrary. And certainly that's true internationally as well. If you want to stand up in Europe or in small islands in the Pacific or in Alaska or in Greenland and say that "nothing is happening," it's a tough sell when reality tells the opposite story. So that makes me optimistic: that over the past 25 years we have learned that the problem is real and ultimately we need to confront it and we need to deal with it.

It also makes me optimistic that there are these young folks who are flexing their muscles. Look at Greta Thunberg. Look at many of her peers who are recognizing that this is their world, too. They will have political power to decide who governs us. They understand this is our world and it's being affected in a bad way by our actions today. That's unstoppable. Then you have the economics of things: The cost curve for solar and wind is coming down dramatically, to the point where those forms of energy generation are now cost-competitive with many forms of fossil fuel energy. We also have the development that—despite the decision of the current administration to initiate the removal of the United States from the Paris Climate Accord—cities, states, companies are saying, "We're in." We recognize that we need to address this problem and that there are economic opportunities inherent in this problem. If we find cheap, efficient ways of providing low-carbon energy, we will be the economic leaders of the 21st century. The economics, the growing power of young people finding their political voices, the growing public awareness of the reality and seriousness of climate change—all of that makes me optimistic about our collective future.

Not just climate scientists, but politicians, the public, voters—you name it—everyone has some say in that debate about the kind of world in which we want to live.

You're getting a lifetime achievement award for your work. What's in your future? Are you going to keep at it?

Absolutely. I'm an old dude now. I've had some opportunity to reflect about the past 25 years, after the "discernible human influence" finding, and to reflect also about where I want to go, what I still want to achieve in whatever amount of time is allocated to me. I remain deeply committed to doing this kind of work. My job is to fingerprint the climate system: to try to separate human-caused signals from the rich, natural variability of the climate system month to month, year to year, and decade to decade. That work is engrossing. It's exciting. I get great joy out of working with younger scientists and trying to mentor them, trying to help them communicate better about the work that they do. I want to continue with that work for as long as I can. On the other hand, I increasingly feel that science is under attack. Climate science particularly is under attack. There are folks who argue in Congress that we don't need to do this work and that it's a hoax, a conspiracy, or that it's something that scientists do in order to feather their own nest or to alter world systems of government. In my opinion, it's critically important to push back against those kind of forces of unreason. We need science. We need data. We need facts in order to make intelligent decisions on how best to respond to the problem of human-caused climate change. So what do we do? How do we address the problem? Not just climate scientists, but politicians, the public, voters—you name it—everyone has some say in that debate about the kind of world in which we want to live. But if we're trying to make those decisions based on misinformation or disinformation or wild zany theories, we're all going to lose. That's not helpful. So part of my job, increasingly, is to try to provide that sound scientific information to the public, so that all of us can make more informed decisions on what to do about it. It's not good enough just to go to my office, close the door, publish a new paper on climate fingerprinting, and hope that somehow, magically, the information from that research will disseminate into the public arena and people will do the right thing. [laughs] I thought that way maybe 35 years ago. I don't think that way now. It's critically important to defend the technical work that you do, to explain what you do and why it matters and why other people should care about it. I want to continue doing that as long as I possibly can.

A podcast interview with the researcher is available online.

LIBERTY
IN GOD WE TRUST
2020
UNITED STATES OF AMERICA
E PLURIBUS UNUM
1 OZ. FINE SILVER~ONE DOLLAR

Introductory Price!
LOW AS
$21.85
each

Actual size is 40.6 mm

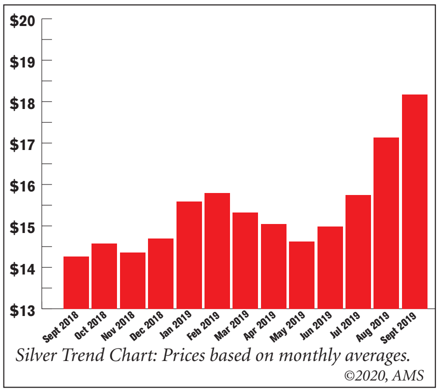
They're Here!

Secure Your NEW 2020 U.S. Silver Dollars NOW

Each year, millions of collectors and silver stackers around the world secure freshly struck American Eagle Silver Dollars. They are perhaps the most widely collected silver bullion coins in the world, and right now, you can be among the first to secure coins from the U.S. Mint's brand-new 2020 mintage!

2019 Was a Great Year for Silver. What Will 2020 Hold?

In 2019, silver prices saw a significant increase. Between Sept 2018 and Sept 2019, silver values increased by 25%! No one can say for sure what the future holds, but these freshly struck, 99.9% pure U.S. Silver Dollars are finally available — meaning the time to buy is NOW!



Silver Trend Chart: Prices based on monthly averages.
©2020, AMS

Brand-New U.S. Silver Dollars

Each hefty U.S. Silver Dollar contains one Troy ounce of U.S. silver, struck in Brilliant Uncirculated (BU) condition by the United States Mint. The 100-year-old design features a walking Lady Liberty draped in a U.S. flag on one side and a majestic U.S. Eagle and shield on the other. These coins are as beautiful as they are desirable — and when silver prices rise, so does demand for these silver coins!

Final Year of Original Design

After 34 years of the Silver Eagle, the U.S. Mint has announced it will change the reverse design for 2021. That makes the 2020 Silver Eagle the last-year of the original design—something collectors crave!

Heads and Tails Above the Rest

Why are we offering you this special price on these new, freshly struck 2020 U.S. Silver Dollars? We're doing it to introduce you to what hundreds of thousands of smart collectors and satisfied customers have known since 1984 — GovMint.com is *the best source for coins worldwide™*.

Timing is Everything

This is a strictly limited offer for one of the world's most popular silver coins — and time is of the essence. Once word gets out that 2020 U.S. Silver Dollars are finally available, and available at such a great price, you'll be facing far more competition. Call today and secure your new 2020 U.S. Silver Dollars ahead of the crowd!

Call Now And Beat the Crowd!

The American Eagle Silver Dollar is one of the best selling and most widely collected silver coins in the world — and buyers are watching the silver markets. Call now and place yourself among the world's top collectors by securing your freshly struck 2020 U.S. Silver Dollars now. Plus, the more you buy, the more you save!

2020 American Eagle Silver Dollar BU

1-4 Coins -	$22.25 each + *s/h*
5-9 Coins -	$22.10 each + *s/h*
10-19 Coins -	$21.95 each + *FREE SHIPPING*
20+ Coins -	$21.85 each + *FREE SHIPPING*

FREE SHIPPING on 7 or More!

Limited time only. Product total over $149 before taxes (if any). Standard domestic shipping only. Not valid on previous purchases.

Call today toll-free for fastest service

1-888-201-7639

Offer Code AEB311-04
Please mention this code when you call.

GOVMINT.COM®
THE BEST SOURCE FOR COINS WORLDWIDE

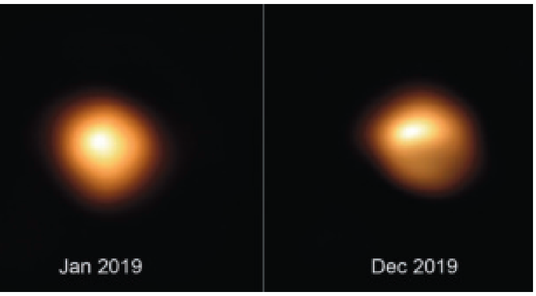
GovMint.com ▪ 14101 Southcross Dr. W., Suite 175, Dept. AEB311-04 ▪ Burnsville, MN 55337

GovMint.com® is a retail distributor of coin and currency issues and is not affiliated with the U.S. government. The collectible coin market is unregulated, highly speculative and involves risk. GovMint.com reserves the right to decline to consummate any sale, within its discretion, including due to pricing errors. Prices, facts, figures and populations deemed accurate as of the date of publication but may change significantly over time. All purchases are expressly conditioned upon your acceptance of GovMint.com's Terms and Conditions (www.govmint.com/terms-conditions or call 1-800-721-0320); to decline, return your purchase pursuant to GovMint.com's Return Policy. © 2020 GovMint.com. All rights reserved.

In this roundup, managing editor Stacey Lutkoski summarizes notable recent developments in scientific research, selected from reports compiled in the free electronic newsletter *Sigma Xi SmartBrief*. Online: https://www.smartbrief.com/sigmaxi/index.jsp

Dust Causes Betelgeuse to Dim

Stargazers hoping to witness a supernova may be in for a disappointment. Astronomers Emily M. Levesque of the University of Washington and Philip Massey of the Lowell Observatory argue that the dimming of Betelgeuse (a star in the constellation Orion) is due to stellar dust blocking the light rather than the star reaching the end of its life. Levesque and Massey used optical spectrophotometry to measure the temperature of the star and found that it was approximately 25 kelvins cooler than in 2004. If the star itself were growing significantly dimmer, then its temperature would have dropped much more. Red supergiant stars, such as Betelgeuse, can periodically slough off an outer layer of material as part of their normal life cycle. This material then condenses into a cloud of dust, which can prevent light from escaping. This theory is reinforced by recent increases in brightness. Although it has not yet returned to its original glow, it seems that Betelgeuse may stick around a while longer.



ESO/M. Montargès et al.

Levesque, E. M., and P. Massey. Betelgeuse just isn't that cool: Effective temperature alone cannot explain the recent dimming of Betelgeuse. arXiv:2002.10463v1 (February 24).

Fish Embryos Can Pause Aging

African turquoise killifish can stop their embryonic development for months or even years as they await more favorable conditions, and they do not age during this period. Geneticists have discovered that this process, called *diapause*, is not passive: The fishes' cells remain active, repressing their metabolism while maintaining muscle health. When the embryos restart their development, their growth, fertility, and life spans are comparable to those of killifish that did not undergo diapause. The process is regulated by the chromobox 7 gene; in tests of fish without the gene, embryos could not stay in diapause for as long, and their muscles deteriorated quickly. African turquoise killifish live in transient ponds in Mozambique and Zimbabwe that dry up and then refill seasonally. The ability to halt killifish development and aging for as long as two years enables them to wait out the dry seasons until the rains return.

Hu, C.-K., et al. Vertebrate diapause preserves organisms long term through Polycomb complex members. Science *doi: 10.1126/science.aaw2601 (February 21).*

Acoustics of Bursting Bubbles

The sound of a bubble popping can reveal the mechanisms behind the explosion. A team at the Sorbonne Université in Paris employed aeroacoustics to study the sound of soap bubbles as they burst. They used an array of sensors to capture the hydrodynamic event and were able to quantitatively identify stressors that caused the bubble to burst. Bubbles are well-tread territory in the field of fluid dynamics, but previous studies have relied on high-speed video to visually examine the growing and popping globes. The use of aeroacoustics is proof-of-concept that many of the elements observed in those videos can also be identified aurally. The aeroacoustic techniques can expand our understanding of how bubbles pop and may provide avenues for studying explosions that we can hear but not see.

Bussonnière, A., A. Antkowiak, F. Ollivier, M. Baudoin, and R. Wunenburger. Acoustic sensing of forces driving fast capillary flows. Physical Review Letters *doi: 10.1103/PhysRevLett.124.084502 (February 27).*

Warm-Blooded Dinosaurs

Fossilized eggshells reveal that all major groups of dinosaurs were *endothermic* (warm-blooded). This evidence is another link between the prehistoric animals and birds. An international team of geologists analyzed the chemical bonds in 75-million-year-old eggshell fragments for evidence of the temperature of the dinosaurs that laid the eggs. In all three major dinosaur groups (Sauropodomorpha, Theropoda, and Ornithischia) they found that the mothers were consistently warmer than their environment, indicating that the animals metabolically regulated their temperature. The findings support the theory that birds evolved from dinosaurs and are another step away from the previous assumption that dinosaurs were prehistoric lizards.

Dawson, R. R., D. J. Field, P. M. Hull, D. K. Zelenitsky, F. Therrien, and H. P. Affek. Eggshell geochemistry reveals ancestral metabolic thermoregulation in Dinosauria. Science Advances *doi: 10.1126/sciadv.aax9361 (February 14).*

New Estimates for 2010 Oil Spill

Invisible and toxic oil from the *Deepwater Horizon* disaster spread much farther than originally estimated. The drilling rig suffered a catastrophic blowout on April 20, 2010, killing 11 people and releasing nearly 800 million liters of oil into the Gulf of Mexico. Satellite images at the time indicated that oil slicks covered approximately 149,000 square kilometers, but new data show a far larger spread. A team of marine scientists paired on-site observations with oil spill transport modeling to examine the extent of invisible and toxic oil in the gulf. They found that the oil reached from Texas to Florida, even wrapping around to the East Florida Shelf. This area extends beyond the boundaries of management actions and continues to affect the Gulf Coast people, businesses, and ecosystems. (*For more information on recovery efforts, see "Renewed Hope for Coastal Marshes in Louisiana," March–April 2019.*) The researchers stress that initial satellite estimates are important for assessing the immediate effects of an oil spill, but ongoing research is necessary to understand the true scope of the damage.

CC-SA/Kris Krüg

Berenshtein, I., C. B. Paris, N. Perlin, M. M. Alloy, S. B. Joyce, and S. Murawski. Invisible oil beyond the Deepwater Horizon *satellite footprint.* Science Advances *doi: 10.1126/sciadv.aaw8863 (February 12).*

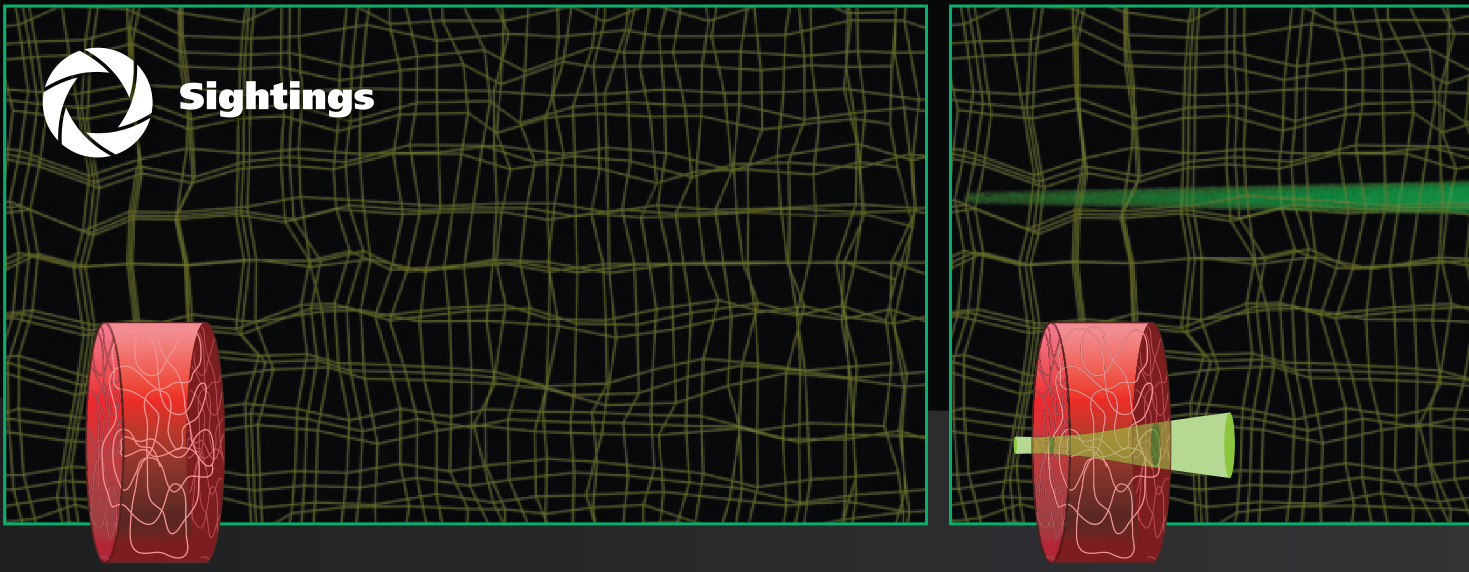
Welcome, New Sigma Xi Members!

Together, we:

support interdisciplinary research
maintain integrity and honesty in all scientific activities
share our results with the world

Visit www.sigmaxi.org to explore the value of membership and locate a chapter near you.

Sigma Xi
The Scientific Research Honor Society



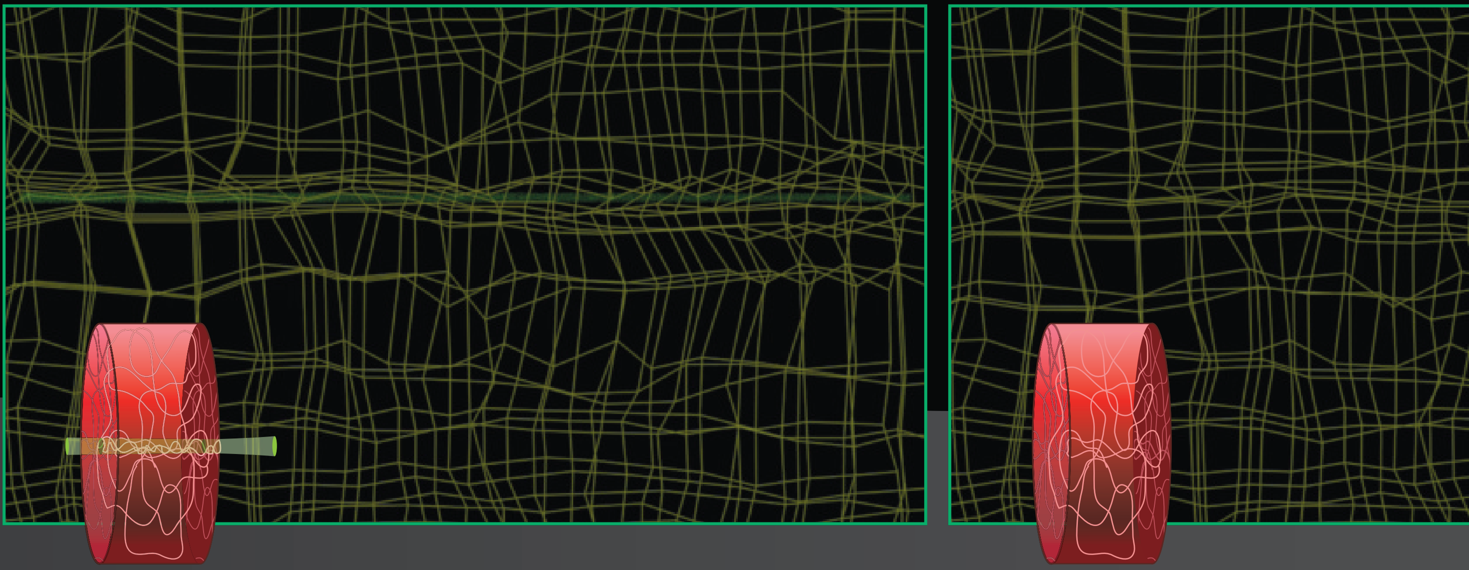
Channeling Lasers

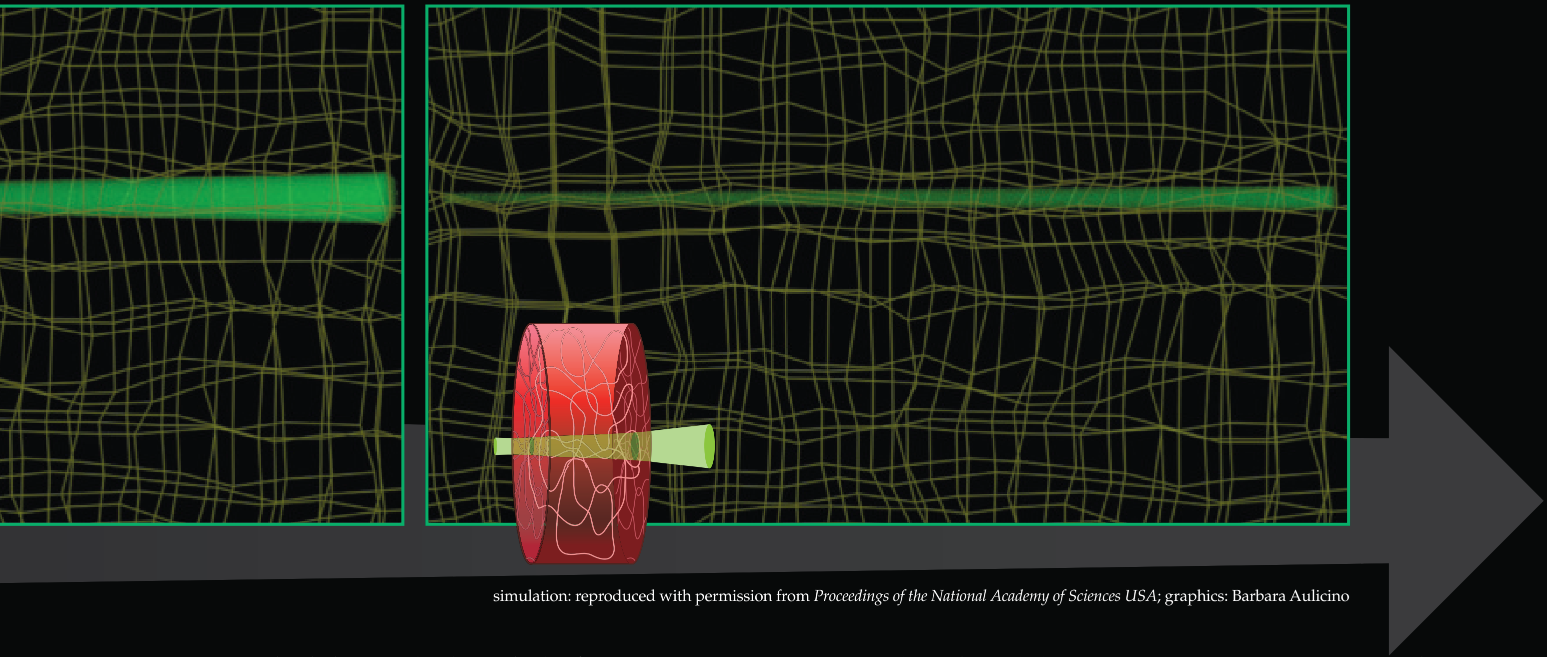
New computing applications are ahead for soft materials that can guide light.

When viewing light that is changing in intensity, molecules in the human eye called *chromophores* undergo transformations that, in turn, prompt nerve impulses to the iris, which then physically opens or closes in response to the changing light intensity. Such feedback loops are common in biological systems, but are rare in synthetic materials because it is a challenge to give synthetic materials those transformational capabilities. One reason researchers undertake that challenge is to make *light-guiding-light technologies*, which may one day provide circuitry-free calculations, light-prompted movement in soft robots, and better targeted-drug therapies.

A team of researchers from McMaster University in Canada, the University of Pittsburgh, and Harvard University have made a synthetic material with a feedback loop similar to that of the human eye. They did it by employing a type of synthesized chromophore called a *spiropyran*—which is like the molecule used for tinting transition lenses in eyeglasses—and embedded it in a *hydrogel*, or a network of cross-linked polymers that can hold a lot of water.

"What happens in our system," says Kalaichelvi Saravanamuttu, a chemist at McMaster University, "is that light triggers the transformation of the spiropyran, which in turn affects the hydrogel itself" with what is essentially a contraction. That contraction squeezes out water from the hydrogel, but only where the light is striking the polymer. That local loss of water means a local difference in the amount of the polymers through which the laser





simulation: reproduced with permission from *Proceedings of the National Academy of Sciences USA*; graphics: Barbara Aulicino

is passing, which keeps the laser light from diverging as it normally would into a cone shape (*see schematic, top middle, top right, then bottom left*).

As the researchers describe in their recent paper in the *Proceedings of the National Academy of Sciences the U.S.A.*, the laser light prompts the creation of a "self-induced optical fiber—that entraps the laser beam . . . and guides it through the medium without diverging." Subsequently, when the laser is turned off, the spiropyran reverses its molecular transformation and the hydrogel expands within seconds, soaking up surrounding water (*see schematic, bottom middle and bottom right; video of the simulation is available online*).

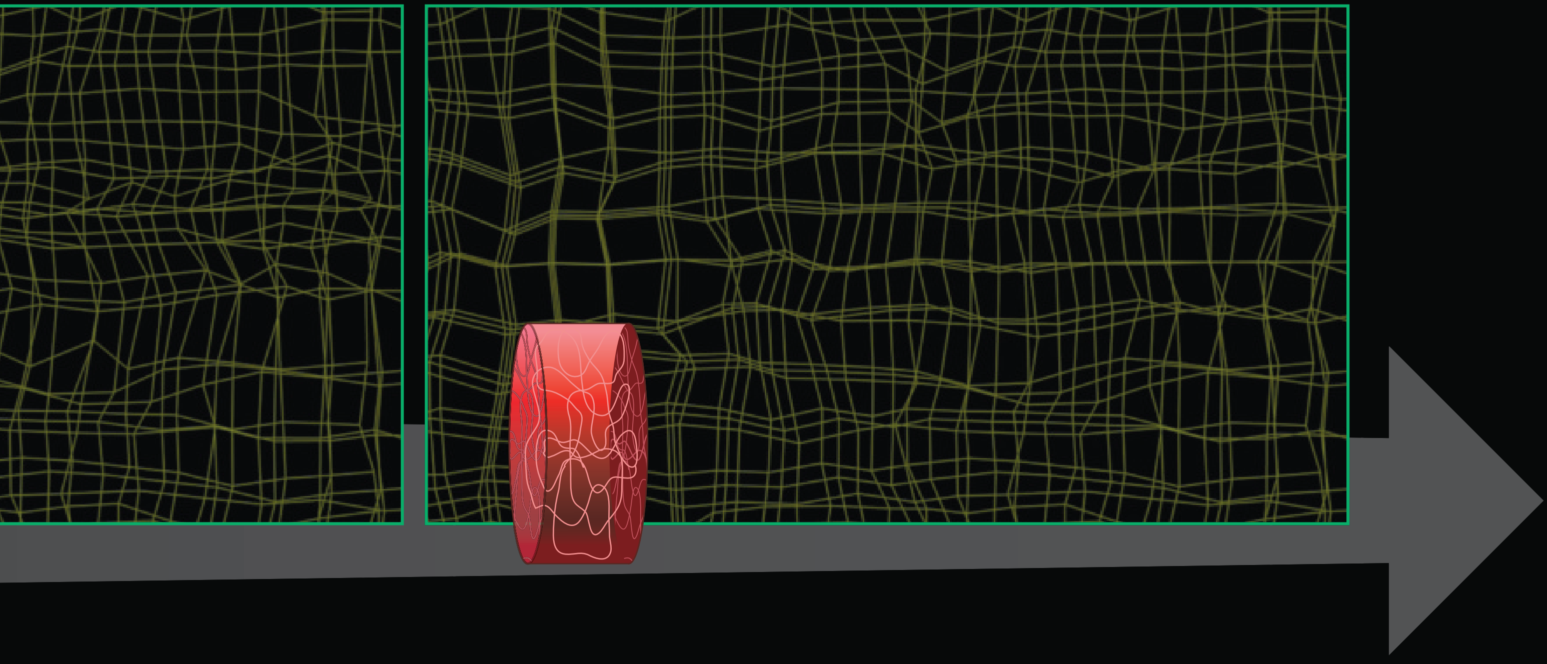
Previous research on these kinds of synthesized light-sensitive hydrogels has mostly focused on static responses under steady-state conditions. "Now we're thinking about how to design materials so that they give you the desired dynamic responses," says Anna Balazs, a chemical engineer at the University of Pittsburgh who worked with Saravanamuttu. The overall design goal, Balazs says, is "to design materials to do simple computational tasks."

Initial tests for that computational capacity involved directing a second, parallel laser beam at the material. Researchers found that it could inhibit the passage of the first beam, be inhibited by the first beam, pass through along with the first beam, or cancel out the first beam. Those kinds of results may correspond to the basic building blocks of computational tasks—called *logic gates*—such as the Boolean functions AND, OR, and NOT.

"It's important to distinguish this work from the very well established work on optical computing, where there is a focus on trying to mimic or to compete with digital computing," Saravanamuttu says. Replacing wired circuits to make an all-optical laptop computer is not the goal, Balazs says, adding, "If you think about new discoveries, it's not appropriate just to think about old applications."

In addition to considering new applications, the discovery also has led to new questions, particularly because the two parallel laser beams interact—affecting one another's transmission through the hydrogel—at greater separation distances than the researchers had expected. Understanding the reason why they still interact will be one subject of study in future work.—*Robert Frederick*

A podcast with the researchers is available online.



Decoding Light from Distant Worlds

Thousands of exoplanets are known, but the compositions of their atmospheres remain at the edge of our knowledge.

Kevin Heng

Modern astronomers now consider the discovery of exoplanets so routine that a Nobel Prize in Physics was finally awarded for exoplanet science in 2019. Thousands of exoplanets (planets orbiting other stars beyond our Solar System) are known to orbit stars in our galaxy, but our knowledge of each exoplanet is generally limited to its size and mass. The next challenge is to develop an inventory of the chemical compositions of their atmospheres—and finally discover what kinds of worlds they are.

Short of mastering interstellar travel, our only means of probing the conditions on exoplanets is via *remote sensing*: deciphering the color of light from a distant exoplanet. These data offer us clues about an exoplanetary atmosphere's formation history and surface conditions. In the short term, studying exoplanetary atmospheres is the only way for us to detect atoms and molecules in an exoplanet without actually traveling light years to get there.

This shift from the detection of exoplanets to the characterization of their chemical properties is an inexorable transition that is occurring within exoplanet science (*see "The Study of Climate on Alien Worlds," July–August 2012*). The Kepler space telescope firmly established the ubiquity of exoplanets. Unfortunately, the vast majority of the exoplanets that Kepler discovered are too far away for astronomers to study their atmospheres. Nevertheless, the Kepler space telescope inspired the next generation of exoplanet-hunting space telescopes (*see "The Next Great Exoplanet Hunt," May–June 2015*). Of these, the Transiting Exoplanet Survey Satellite (TESS) is fully operational and reporting discoveries of exoplanets orbiting the nearest, brightest stars. The Characterizing Exoplanet Satellite (CHEOPS) launched in December 2019; the cover of the telescope opened on January 29, and the telescope is currently in its commissioning phase.

The nearby "golden target" stars and their transiting worlds are key for the next phase of exoplanet science. The objective is not only to perform surveys of the bulk properties (such as size or mass) of exoplanets but also to construct a catalog of their atmospheric properties. Astronomers hope the giant space telescopes equipped with state-of-the-art spectrographs will reveal these properties in the near future with the James Webb Space Telescope (*see* Perspective, *March–April 2017*) and perhaps in the distant future with proposed missions such as LUVOIR (*see* Perspective, *September–October 2018*).

From our vantage point on Earth, some fraction of stars will have exoplanets residing in nearly edge-on orbits with respect to us. As the orbiting exoplanets obscure a part of their stars, a tiny dip occurs in light from the system; this process is known as a *transit*. If the exoplanet possesses an atmosphere, the depth of the transit varies with the color of the light (wavelength). This variation happens because atoms and molecules absorb light to different degrees depending on their color, which is quantified by a measurement known as the *cross section*. Researchers obtain these cross sections by performing quantum mechanical calculations on computer and laboratory measurements.

A thought experiment illustrates this mapping: Consider an exoplanet with an atmosphere that consists purely of gaseous water. At wavelengths where water is opaque to light, the size of the exoplanet—and thus its transit depth—will appear slightly larger. Conversely, at wavelengths where water is transparent to light, the exoplanet will appear comparatively smaller. For example, water absorbs more light at around 1.4 micrometers—in the near-infrared range of wavelengths. This principle guides astronomers who use the Wide Field Camera 3 (WFC3) on board the Hubble Space Telescope to probe exoplanets for water.

This general principle underlies the technique of *transmission spectroscopy* and may be used to search for any atom or molecule as long as we have knowledge of its cross section. The change in apparent size is a powerful tool, but it amounts to no more than a few percent change in a signal that is already tiny, which makes it a challenging measurement. The signal

QUICK TAKE

A new challenge in exoplanet science is evaluating the chemical compositions of the atmospheres of worlds orbiting stars outside our Solar System.

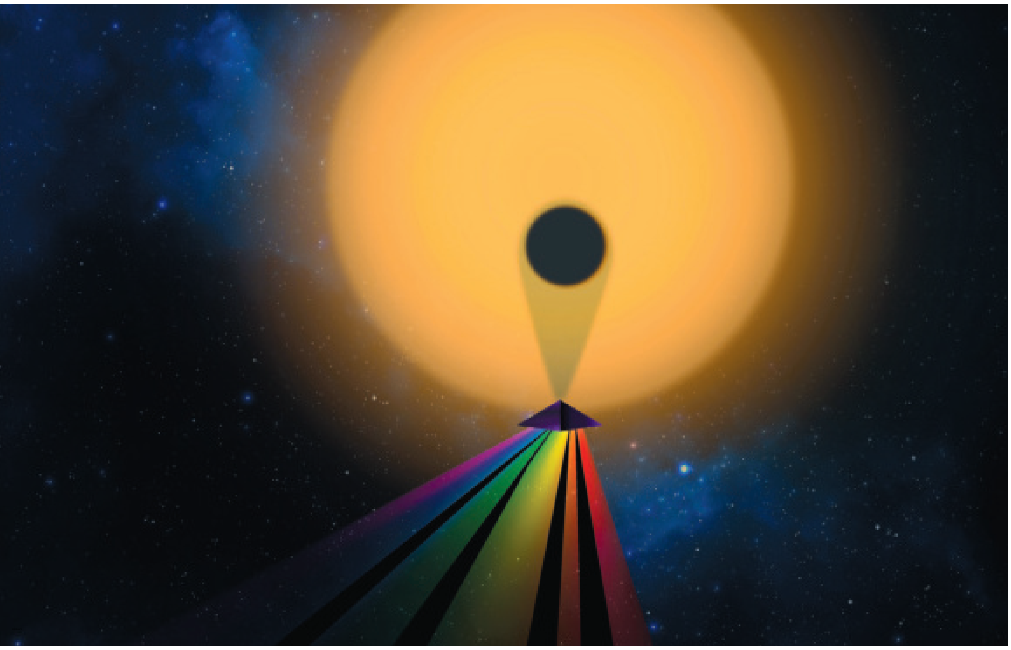
Because the data are sparse, astronomers examine a molecule's abundance across a large sample of exoplanetary atmospheres to uncover trends about the planets' formation.

Regarding gases that suggest life is present, confusion arises from false positives when geochemical cycles also produce the gas, and false negatives when a trace gas is missed.

is maximized when researchers use transmission spectroscopy to scan very strong spectral lines of atoms and molecules, called *resonant lines*. A famous example of resonant lines are the Fraunhofer D-lines of the sodium atom (which absorb yellow light visible to the human eye), named after the German physicist Joseph von Fraunhofer, who studied them.

In a pioneering paper published in the *Astrophysical Journal* in 2000, Sara Seager of Massachusetts Institute of Technology and Dimitar Sasselov of Harvard University predicted that the sodium atom, which strongly absorbs light in the visible range of wavelengths, would be easily detected via transmission spectroscopy. (*See "What's Next for Finding Other Earth-Like Worlds?" September–October 2018.*) Two years later, David Charbonneau of Harvard University and his collaborators reported the detection of sodium in the gas-giant exoplanet HD 209458b. Seager and Sasselov also predicted the detectability of helium in the near-infrared, but its discovery was not confirmed until 2018 by independent teams of astronomers. Since its first discovery in 2002, the detection of sodium in transiting exoplanets has become routine using ground-based telescopes equipped with state-of-the-art spectrographs such as the High Accuracy Radial Velocity Planet Searcher (HARPS) on the 3.6-meter telescope at La Silla Observatory in Chile. Sodium was a great test case, even though it is not a biosignature. Once it was clear that transmission spectroscopy could be used to detect sodium, it opened the floodgates to finding other atmospheric gases this way.

Transmission spectroscopy has been demonstrated to work for several species of atoms and molecules, including water, carbon monoxide, methane, potassium, iron, and titanium. These discoveries tend to be made in large, gas-giant exoplanets not unlike Jupiter in our Solar System—except that their atmospheric temperatures tend to be 1,000 kelvins or higher. Hydrogen and helium dominate the atmospheres of these exoplanets, implying a fluffy atmosphere with large variations in the spectral features of atoms and molecules. Trace molecules such as water, present at one part in a thousand or less, are detectable in such hot, fluffy atmospheres. Because these measurements are so challenging to make, transmission spectra obtained using the Hubble Space Telescopes tend to consist of about a dozen data points—landing us firmly in the regime of sparse data. Smaller, cooler exoplanets that might resemble Earth are out of Hubble's reach.



Christine Daniloff/MIT, Julien de Wit

When an exoplanet passes in front of its star, the light passing through its atmosphere lends clues to what gasses are present. But the data are sparse and require considering many contingencies. Exoplanetary scientists are developing new methods and standards to meet these challenges.

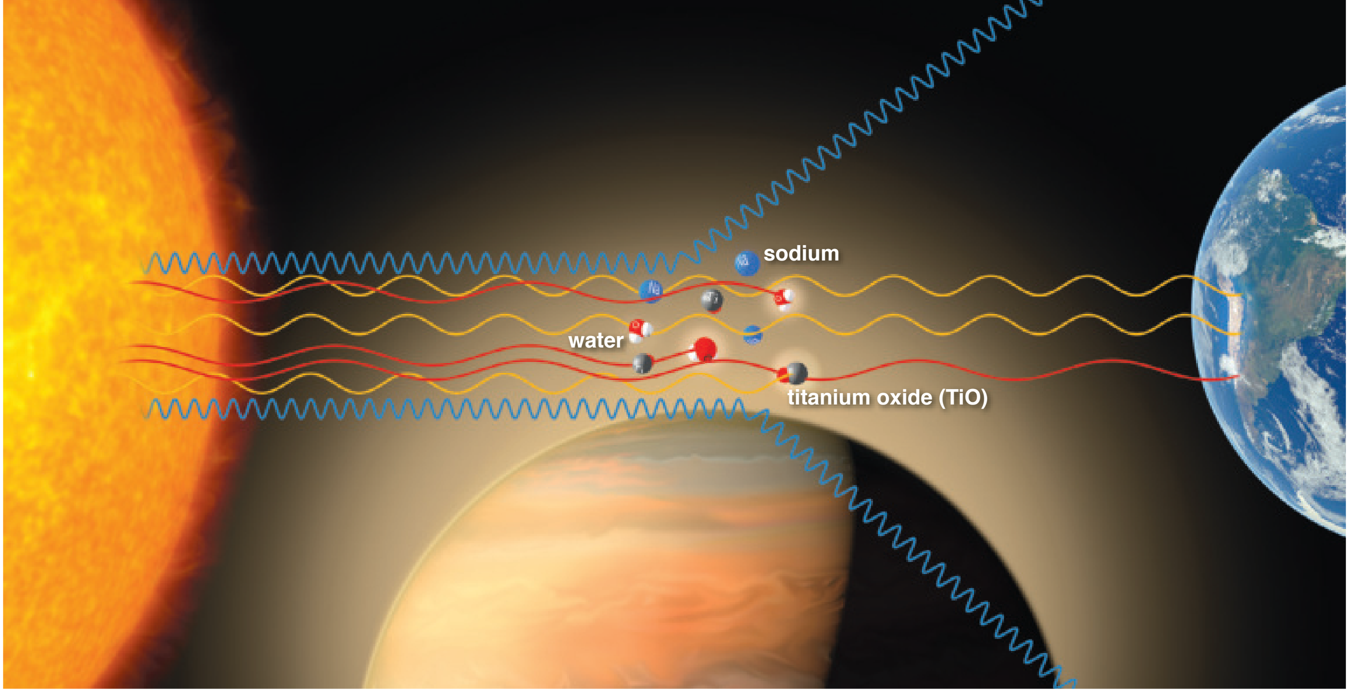
Analyzing Sparse, Important Data

Obtaining hard-earned data from a space telescope is only the first step; fully appreciating the information encoded within the data is the next step. The interpretation of sparse data requires understanding and shrewdly applying the tools of statistics. Instead of receiving a single answer from interpreting the data, researchers obtain a range or distribution of answers expressed as probabilities. The concept of what a probability means depends on the statistician's school of thought. *Frequentists* view probabilities as the number of times an event occurs if one could perform an infinite number of equally probable trials—theoretical ideals that are difficult to reconcile with actual practice. *Bayesians*, on the other hand, regard probabilities as measuring degrees of belief about a hypothesis.

In a 2008 review article, Roberto Trotta of Imperial College London makes the case for the Bayesian school of thought: "The discovery zone for new physics is when a potentially new effect is seen at the 3- to 4-sigma level. This is when tantalizing suggestion for an effect starts to accumulate, but there is no firm evidence yet. In this potential discovery region, a careful application of statistics can make the difference between claiming or missing a new discovery." In other words, a careful application of Bayesian inference allows us to consider scientific results at the bleeding edge of research.

In the classical approach, a researcher makes a theoretical prediction for what the transmission spectrum looks like and then compares it to data. A "goodness of fit" criterion is evaluated, and the theoretician declares victory or failure of the model's ability to match data (or be decisively confronted and ruled out by it). When dealing with sparse data, one needs to execute a mental shift: There are now families of theoretical models that may be consistent with the data to different degrees. In the context of decoding transmission spectra, one has to ask, What is the appropriate level of sophistication that is warranted in the theoretical model, given the quality of the data? It is essentially the application of Occam's razor: Given a family of models, the least sophisticated one is preferred—at least until better data are available to overturn the hypothesis.

In a less abstract example, is the water molecule alone sufficient to explain



ESO/M. Kornmesser

When an exoplanet passes in front of a star, some wavelengths of light passing through the molecules in its atmosphere are absorbed or refracted. Astronomers study the properties of the exoplanet and the wavelengths of light reaching Earth to consider which gases are present in its atmosphere. Yellow light, for example, can be absorbed by titanium oxide, and red light can be absorbed by water vapor.

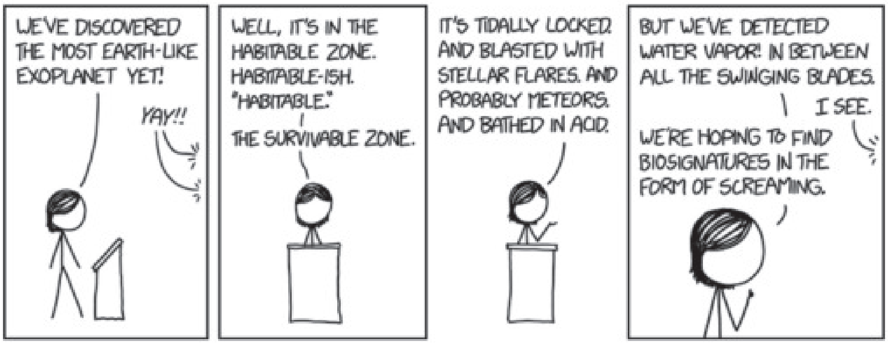
the bumps and dips in the transmission spectrum? Or are other molecules such as ammonia present and needed to explain the patterns observed? Are there sharp changes in temperature that need to be accounted for? Are clouds present that are made up of exotic particles (for example, olivine)? The theoretician proceeds to calculate transmission spectra for all these possibilities and compares them to the data. Associated with each model is a quantity known as the *Bayesian evidence*. By comparing the Bayesian evidences between models, one may identify the family of models that is consistent with—but not necessarily proven correct by—the data. One may also identify models that the data rule out. This Bayesian model comparison informs us that water is confidently detected in the dozens of transmission spectra the Hubble Space Telescope has measured so far, with claims for other molecules generally requiring further corroboration from future space telescopes.

By measuring water abundances from a large sample of exoplanets, astronomers hope to uncover trends in the sample that offer hints on how they formed. Researchers may use hydrogen-dominated, gas-giant exoplanets in such an experiment, because to a good approximation their atmospheric compositions resemble those of their host stars. Variations in the abundances of molecules within their atmospheres arise when they form in different locations within a primordial disk of dust and gas around their stars. Farther away from the star, the temperatures drop and molecules freeze into their solid phases. These locations around the star are known as *ice lines* (or *snow lines*). The water ice line occurs first, followed by that of carbon dioxide and carbon monoxide. As these molecules freeze, they become unavailable for incorporating into the atmosphere of the gas-giant exoplanet. It is then not hard to imagine that, depending on where the exoplanet formed relative to these ice lines, the oxygen content of the gaseous atmosphere will vary. If most of the oxygen is subsequently locked up in gaseous water, then measuring the abundance of water will provide a direct constraint on the oxygen content and hence the formation history of the exoplanet. Several caveats, which are at the forefront of active research, complicate this narrative, including the possibility that some of the oxygen may be sequestered by other molecules that do not announce their presence in the transmission spectrum.

For rocky exoplanets, it will be much tougher to infer their formation history from their atmospheric compositions. Gas-giant exoplanets have *primary atmospheres* that reflect their history of formation. Rocky exoplanets are expected to have *secondary atmospheres* that are controlled by geochemical cycles. For example, the carbonate-silicate cycle or long-term carbon cycle on Earth regulates the amount of carbon dioxide—a potent greenhouse gas—present in the terrestrial atmosphere.

With rocky exoplanets that may resemble Earth, the scientific question is rather one of whether biology is present on their surfaces. Gases that robustly indicate the presence of biology are known as *biosignatures gases.* Such gases would need to be produced in large

Earthlike Exoplanet


WE'VE DISCOVERED THE MOST EARTH-LIKE EXOPLANET YET!
YAY!!
WELL, IT'S IN THE HABITABLE ZONE. HABITABLE-ISH. "HABITABLE."
THE SURVIVABLE ZONE.
IT'S TIDALLY LOCKED AND BLASTED WITH STELLAR FLARES. AND PROBABLY METEORS. AND BATHED IN ACID.
BUT WE'VE DETECTED WATER VAPOR! IN BETWEEN ALL THE SWINGING BLADES.
I SEE.
WE'RE HOPING TO FIND BIOSIGNATURES IN THE FORM OF SCREAMING.

www.xkcd.com/CC-BY-205

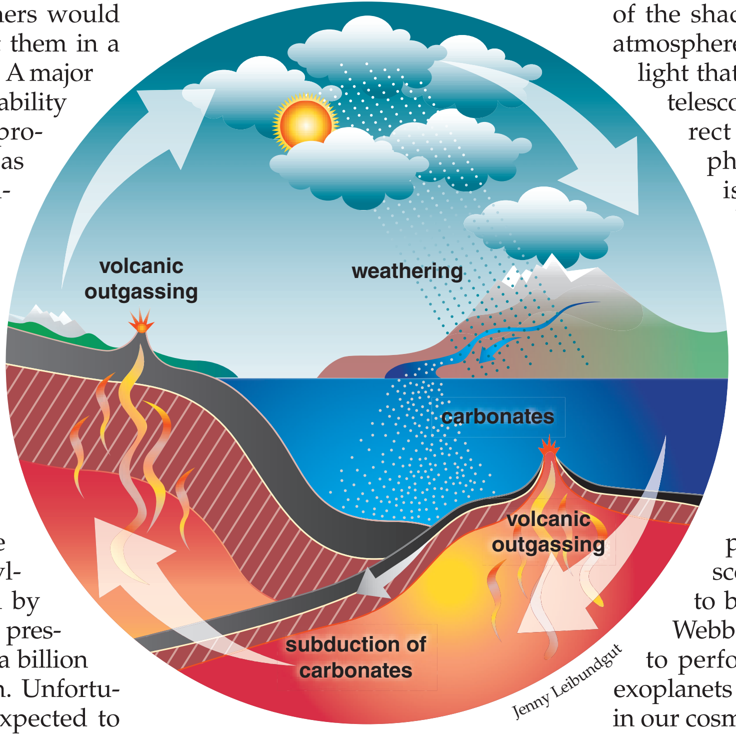
enough amounts that they would imprint their signatures on the transmission spectrum of the exoplanet. They would have to be stable over geological timescales, because if they exist for only a fleeting instance in the history of the exoplanet, astronomers would have little chance to detect them in a sample of rocky exoplanets. A major source of confusion is the ability of geochemical cycles to produce the same gases, such as carbon dioxide and methane, without the participation of biology—thus creating *geological false positives* that mimic biosignatures. Seager calls these *Type I biosignatures*. Biosignatures that cannot be mimicked by geology are *Type III biosignatures*, but they are expected to be present in vanishing amounts. On Earth, a Type III biosignature is dimethylsulfide, which is produced by tiny plants in the ocean and present at less than one part in a billion in the atmosphere of Earth. Unfortunately, biosignatures are expected to be beyond the reach of even the James Webb Space Telescope.

The Grand Challenges

From the viewpoint of decoding the transmission spectrum, one would either have to collect a rich inventory of Type I gases (such as methane and ammonia) and assess the probability of their presence being due to biology, or one would have to attempt to dig out the faint signature of a Type III biosignature among a forest of spectral lines from other, abiotic molecules. This grand challenge faces the next generation of exoatmospheric scientists as giant space telescopes with the sensitivity and wavelength coverage to make these measurements come online.

Other challenges await the measurement and interpretation of transmission spectra of rocky Earth-sized exoplanets. If the atmosphere is nitrogen-dominated (like Earth's), then variations in the spectral features of atoms and molecules shrink by a factor of 10, making them much harder to detect. Some of these signals may be buried in the noise produced in the infrared detectors and by the mode of telescope operation. Furthermore, as the size of the exoplanet shrinks relative to its star, contamination by imperfections on the stellar surface, such as star spots, become an increasing concern. Refraction, the bending of light rays because of variations in density, becomes an effect that cannot be ignored in transmission spectroscopy. All these factors culminate in the opinion, held by a part of the exoplanet community (including myself), that although transmission spectroscopy is useful for studying gas giants orbiting Sun-like stars (or Earth-sized exoplanets orbiting small red-dwarf stars such as TRAPPIST-1), it is probably not the optimal technique for studying the "Earth twins"—Earth-sized exoplanets orbiting Sun-like stars. In the next few years, the community's best shot at understanding the habitability of Earth-sized exoplanets will be to apply transmission spectroscopy to those orbiting small red-dwarf stars.

Carbonate–Silicate Cycle



Jenny Leibundgut

The long-term carbon cycle, also known as the *carbonate–silicate cycle*, regulates the inventory of carbon dioxide in the Earth's atmosphere on a timescale of several hundreds of thousands of years. Water, rock, and carbon dioxide produce carbonates through weathering. They then sink to the bottom of the ocean and are subducted into the Earth's mantle. Outgassing via volcanos returns the CO$_2$ to the atmosphere. The cycle functions as a thermostat, regulating temperatures over geological timescales. Because of such geochemical cycles, rocky exoplanets' atmospheres do not reflect the history of their formation, as is true for gas-giant exoplanets.

No photons from an exoplanet are measured during transmission spectroscopy. Rather, current techniques rely on measuring the size of the shadow the exoplanet and its atmosphere cast on its star. The only light that enters the detectors of the telescope is from the star. The direct measurement of infrared photons from the exoplanet is immensely challenging, because the star outshines the exoplanet by a factor of a million to a billion, depending on the color of light being measured. Direct imaging relies on sophisticated techniques, implemented both via hardware and software, to suppress starlight. It is the technique that the proposed LUVOIR space telescope, pitched as a successor to both the Hubble and James Webb space telescopes, will use to perform a census of Earth-like exoplanets and hunt for biosignatures in our cosmic neighborhood.

Kevin Heng is professor of astronomy and planetary science at the University of Bern, Switzerland, where he also serves as the director of its Center for Space and Habitability. He is an honorary professor in the department of physics at the University of Warwick in the United Kingdom. He is a core science team member, representing Switzerland, on the CHEOPS mission of the European Space Agency. He is the author of the 2017 book, Exoplanetary Atmospheres: Theoretical Concepts and Foundations*. Twitter: @KevinHeng1*

Bibliography

Brown, T. M. 2001. Transmission spectra as diagnostics of extrasolar giant planet atmospheres. *Astrophysical Journal* 553:1006–1026.

Charbonneau, D., et al. 2002. Detection of an extrasolar planet atmosphere. *Astrophysical Journal* 568:377–384.

Deming, D., and S. Seager. 2017. Illusion and reality in the atmospheres of exoplanets. *Journal of Geophysical Research: Planets* 122:53–75.

Seager, S., and D. Sasselov. 2000. Theoretical transmission spectra during extrasolar giant planet transits. *Astrophysical Journal* 537:916–921.

Seager, S., W. Bains, and J. J. Petkowski. 2016. Toward a list of molecules as potential biosignature gases for the search for life on exoplanets and applications to terrestrial biochemistry. *Astrobiology* 16:465–485.

Trotta, R. 2008. Bayes in the sky: Bayesian inference and model selection in cosmology. *Contemporary Physics* 49:71–104.

The Hard Hat

Illustrations and photographs have helped document how protective headwear came into common use in construction projects.

Henry Petroski

Jens Büttner / AP Images

The modern hard hat has come a long way from its first iteration, which was made from alternating layers of canvas and glue and then "hard boiled" into shape. Modern hard hats have an inner suspension system to prevent impact energy from transferring to the skull.

The hard hat has become ubiquitous on construction sites, on the heads of engineers, construction workers, and visitors alike, but this was not always the case. I am not aware of pictorial evidence that any specialized head or body protection was used on ancient building projects, as dangerous as working on them must have been.

Depictions of Egyptian pyramid workers show them in little but a loincloth, called a *shendyt*, and maybe a head covering that looks like today's handkerchief or thin cap. This covering may have provided some relief from the Sun, but would have been of no help against even a small piece of stone dropped from a significant height. Some people in the illustrations do appear to be wearing more extensive head covering, but judging by where and how they are positioned among the work crew, archaeologists surmise that these persons were likely supervisors. So far, excavations of worker cities and burial grounds haven't turned up any evidence of protective headwear.

The creation, transportation, and erection of the tapered monoliths known as obelisks presented another challenge in ancient Egypt. These slender shafts, often made of red granite from Aswan, consisted of a single piece of stone and could weigh as much as 500 metric tons, or two orders of magnitude greater than a pyramid's individual building block. Exactly how workers removed stone for an Egyptian obelisk from the quarry, moved it to its destination, and raised it to a vertical position remains a subject of speculation.

The sides of the Egyptian obelisk relocated to the Place de la Concorde in Paris in 1833 are inscribed with hieroglyphics relating to the reign of Rameses II (1279–1213 BCE), in whose honor it was first erected at Luxor. There is no mention of workers; the pedestal of the granite shaft contains diagrams depicting how the monolith was lowered, transported, and raised into its present position, but these illustrations were made contemporaneously with the modern reloca-

Henry Petroski is the Aleksandar S. Vesic Professor of Civil Engineering and a professor of history at Duke University. His most recent book is The Road Taken: The History and Future of America's Infrastructure. *Address: Box 90287, Durham, NC 27708.*

tion. The diagrams show ropes, pulleys, and struts being employed to move the monolith, but no workers, who seem to have been valued for their brawn but not their individual identities.

There exists one dramatic depiction of ancient Egyptian workers hauling a much larger-than-life-size 58-ton statue of Djehutihotep, a nomarch of the Middle Kingdom (circa 1900 BCE). The colossal task was depicted in a wall carving in the tomb of this provincial governor, and showed a team of 172 workers involved in the task. In 1890, the carving was destroyed in an act of vandalism, but a photograph had already been taken. It does not show the workers wearing any head protection.

Images from the Renaissance provide more definitive depictions of workmen involved in herculean tasks, and the most famous of these are the etchings made by the Italian artist Natale Bonifacio for Domenico Fontana's *Della trasportatione dell'obelisco Vaticano et delle fabriche di nostro signore papa Sisto V*, his meticulous 1590 account of the 1586 relocation of the Vatican Obelisk. The feat of engineering involved some 900 men, 75 horses, and many pulleys and ropes. In some of Bonifacio's etchings, workmen appear to be virtually naked save for what looks to be some soft covering of the head that would not provide much protection from anything dropped from the top of the almost 30-meter-tall scaffold constructed for the task.

Recorded for Posterity

Joseph Nicéphore Niépce of France is credited with inventing photography, and his 1826 *View from the Window at Le Gras* is believed to be the oldest surviving photograph. It captured a scene on his estate. The buildings and rooftops in the foreground were typical subjects of many early camera shots, chosen because they were static and thus allowed long exposure times without the image becoming blurred.

The camera improved greatly through the course of the Victorian era, and had become a familiar device by midcentury. *The Pencil of Nature*, by British photography pioneer Henry Fox Talbot, was published serially between 1844 and 1846. It was the first book illustrated with photographs and published for the trade. Among the illustrations were photos of a street scene, a collection of objects on shelves, and a broom resting against a doorway. One photo includes some men, but to prevent blurring they are holding onto things that could steady them throughout the long exposure.

Photographing active construction sites and the completed structures became common, and such images that have survived provide invaluable records of how important engineering achievements had looked during their building and immediately after their completion. Among these images are ones of the critical steps in the erection of the Britannia Bridge across the Menai Strait in Wales, one of the outstanding heroic engineering projects of the mid-19th century. Another celebrated construction project of the time was the building of the Crystal Palace in London's Hyde Park. This enormous iron-and-glass structure was built in record time to house the Great Exhibition of the Works of Industry of All Nations of 1851—essentially the first world's fair. One photograph shows details of its facade in sharp focus, but the flag flying atop its transept is badly blurred because it was flapping in the wind throughout the camera's exposure time.

Throughout the 19th century, construction workers appear to have carried out their activities in street clothes, including their everyday caps.

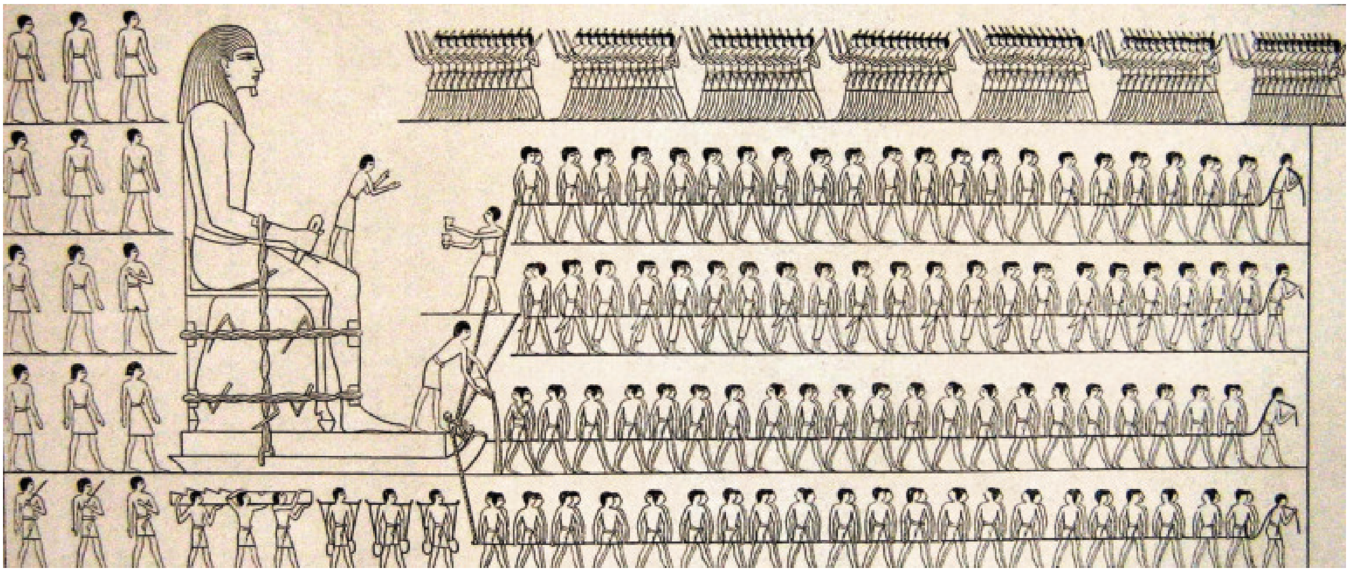
Increasingly, photographers began to include pictures of people working on construction sites—and as subjects in their own right. The setup of such photos of workers mimicked more formal photos of the time, where an individual was seated in a chair fitted with an inconspicuous head rest, or standing beside furniture on which they could place a hand to steady themselves during the long exposure time. In vintage photographs of construction sites, workers were similarly posed, but instead of furniture, they were sitting on or holding onto a large piece of equipment or a partially or newly completed structure.

Prominent and closely followed construction projects, such as that of the Brooklyn Bridge, completed in 1883, were photographed many times in various stages of progress. In one famous photo, a half dozen men are standing close together on a temporary catwalk bearing a sign declaring that it was "safe for only 25 men at one time. Do not walk close together nor run, jump, or trot. Break step." The cautionary message was signed "W. A. Roebling, Eng'r in Chg." The men are too well dressed to be workers; half of them are wearing top hats. The man in the foreground appears to be Washington Roebling, who had become chief engineer of the project when his father, John Roebling, died after a construction accident. Other Brooklyn Bridge construction photos and engravings show actual workers, and their headwear is of a kind much lower and softer than a top hat. Throughout the 19th century, construction workers appear to have carried out their activities in street clothes, including their everyday caps.

Safety First

The modern hard hat first came into use not on towering bridge projects but in underground mines. These confined spaces typically had low ceilings, perhaps shored up with post-and-lintel timberwork, which lowered the headroom even more. It was common for a coal miner to have loose anthracite fall on him or to hit his head on one of the horizontal timbers, an action that could result in more than a bump. At the end of the 19th century, miners were wearing a form of head protection made of leather. An improved means of protection was revealed in a 1919 patent for a "hard-boiled hat," which was made up of layers of canvas interspersed with glue and steamed into shape.

The hard-boiled hat was the invention of Edward W. Bullard, who was the son of the founder of the E. W. Bullard Co., which made protective leather hats and other mining supplies. Upon returning from service in the world war, the young Bullard conceived of a hat inspired by the steel helmets used abroad to ameliorate the effects of bomb blasts on the battlefield. He saw it as a natural product to sell to a construction industry that was building ever higher skyscrapers, bridges, and other structures. The original Bullard leather model somewhat resembled the deerstalker hat associated with Sherlock Holmes. In time, the



Wikimedia Commons

In this copy of an Egyptian illustration, hundreds of workers move a giant statue of a provincial governor. In performing such arduous tasks, Egyptian workers are never depicted in protective headwear.

double bills were extended all around the hat to form a single brim that could deflect objects falling from every angle. The wraparound feature also made the hat more closely resemble the soldier's helmet that inspired it.

In the 1920s the hard hat emerged from the darkness of the mines into a bright future. It soon became obvious that a highly desirable improvement to the hard-boiled hat would be a means of separating the hat proper from the head on which it rested. Without an internal suspension system that allowed a bit of space between hat and head, the impact from a falling object was transmitted directly to the skull. One quick and easy alternative to the Bullard hat was to stuff a bowler or derby hat with wadded-up newspaper, thus providing a cushion against impacts. Electricians claim to have been the first construction workers to use hard hats. In the late 1920s some telephone linemen in Boston began wearing surplus army helmets to protect themselves from hot rivets falling from a nearby 25-story building under construction. The repurposed headgear became known as "steel derbies."

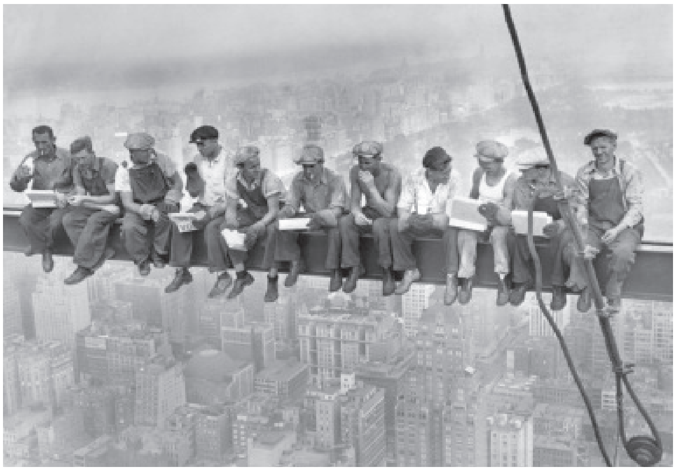
Steel and aluminum hard hats conduct electricity, however, making alternative materials preferable for anyone working around live wires. In time, manufacturers made hard hats of Bakelite, fiberglass, and plastic, as those new materials became available. Until then, the old ones prevailed.

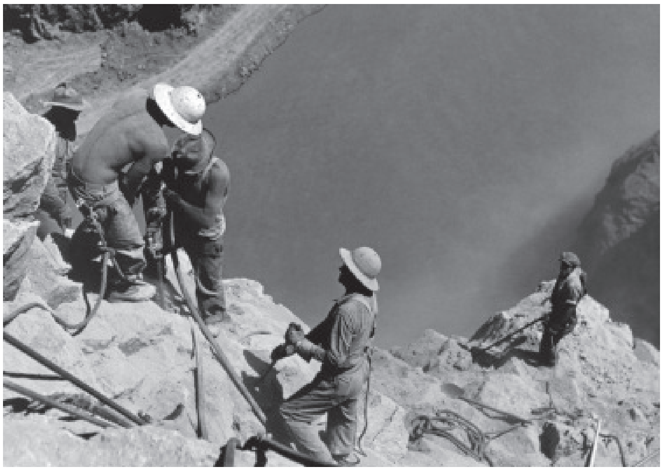
Two very prominent construction projects in the 1930s were Hoover Dam and the Golden Gate Bridge. They were also among the most widely reported early adopters of the hard hat. To prepare the steep sides of Black Canyon for the dam, workers had to remove cracked and loose rock. The men responsible for doing this were known as *high scalers,* and they worked while hanging from ropes anchored atop the canyon. As a high scaler made his way down the canyon wall, rock debris loosened by other high scalers rained down on him. At first, the obvious dangerousness of the situation prompted some workers to dip their soft hats in tar, thereby coming up with a homemade form of hard hat. They soon started using ready-made Ballard hats; when the contractor Six Companies saw the hats' benefits, it procured and issued hard-boiled hats to all workers.

The Hoover Dam project also involved driving tunnels through the rock walls lining the canyon to divert the Colorado River during construction of the dam. The tunnels had to be lined with concrete so that a smooth surface was presented to the flowing water. The lining was poured behind wooden forms, which remained in place until the concrete had set. Once, when the forms were being removed, it appeared that a worker had been entombed in the lining. In fact, the "body" was a pair of empty overalls and a hard hat that had been arranged in the wet concrete to give the impression that a man was buried in it. Some joke! Its perpetrators were tracked down and fired by the legendary dam engineer Frank Crowe, whose nickname was "Hurry Up." He did not want foolishness any more than accidents to slow down the schedule of his construction project.

Meanwhile, on the West coast, the enormity of the Golden Gate Bridge across the entrance to San Francisco Bay meant that construction crews worked high above the strait. The bridge's towers were to be more than 225 meters tall, and at high tide the roadway would be suspended some 65 meters above the water. Thus, anything dropped from the top of the tower could fall more than 150 meters before hitting a worker on the deck, and a worker on the deck could fall more than 60 meters to the water. To protect against such incidents, two steps were taken: Netting was placed beneath the deck, and all workers were required to wear hard hats capable of deflecting the hot rivets used by others working on the project.

Workers elsewhere often had to be coaxed into wearing hard hats, even when they were made available in large numbers at the entrance to a construction site, where they also had to be dropped off after a work shift. For purposes of hygiene, however, most workers preferred to have their own head protection, and eventually construction workers began to wear personalized hard hats even on their commutes. In time, as Beth Rosenberg and Charles Levenstein of Tufts University School of Medicine have written in an article about social factors in occupational health, hard hats achieved the status of being a "cachet and are often worn even when they are not required."


Ullstein Bild/Granger


Photograph by Ben Glaha/Granger

New York construction workers eat lunch on a Rockefeller Center beam in 1932, 260 meters above street level. Although the photo is staged, the lack of protective headwear was accurate. By contrast, the Hoover Dam, constructed from 1931 to 1936, saw acceptance of hard hats on workers.

Engineers who frequently had to visit project areas came to hang hard hats in their offices, always at the ready for a trip to a construction site to check on progress or a problem. Having one's own hat meant that once its suspension system was adjusted to fit, it could be put on without a second thought. The hard hat of an office-bound engineer who visits a construction site only occasionally has a good chance of remaining pristine. "Seasoned craftsmen," on the other hand, "usually have old, scratched, and dull hats, reflecting many hours of hard work and which serve as status indicators," according to Rosenberg and Levenstein. On some construction sites there is a color code for hard hats to represent worker specialty and engineer hierarchy. Although the code is not universal, a white hat often signifies an engineer or manager, and different color hats make it easy to distinguish ironworkers from carpenters, for example. Visitors to a construction site today must wear a hard hat, but they are often loaned one whose color does not identify them as such.

Setting Standards

The incontrovertible practical benefits of hard hats, publicized during widely reported Depression-era construction projects, naturally led to their broader adoption and continued development. Hard hat use also contributed to the establishment of the Occupational Safety and Health Act, which the U.S. Congress passed in 1970. This legislation created the Occupational Safety and Health Administration (OSHA), which sets standards that govern safety issues in the construction and other industries, including guidelines for the design of hard hats and where they must be worn. Among the requirements are that a hat's design must protect against impact, penetration, and electrical shock—this last requirement pretty much marked the end of metal hats. The typical hard hat today is made of sturdy and durable plastic, such as high-density polyethylene or polyetherimide, and is formed by injection molding. Among the benefits of plastic is that its color does not chip or scratch off.

According to OSHA, a hard-hat design should be tested to demonstrate its compliance with the agency's expectations. I once observed the comparative testing of hard-hat designs using an electrohydraulic impact machine located in a structural engineering laboratory. A test consisted of subjecting a hat to a controlled high-speed impact, and then recording its tolerance for the impact force and determining if it became cracked or more significantly damaged. Manufacturers of hard hats today must not only comply with OSHA rules and standards but also be able to claim (and be prepared to back up with evidence) the superiority of one design over another.

Engineering News-Record, the weekly magazine of the construction industry, frequently contains photographs of new and innovative projects. Sometimes a cover story will show workers dramatically engaged in some dangerous task, such as preparing the reinforcing materials for a concrete bridge designed to span a deep valley, or installing the topping-out steel beam on a new high-rise building. When regular readers of this publication, who have come to expect a hard hat as a commonplace part of the construction scene, notice a bareheaded worker in such a photo—anecdotal evidence that a safety rule was being violated—they will write letters to the editor as scathing as those written by an English major who catches an unforgivable typographical error in a literary journal.

Although brain trauma in football players and related advances in that sport's helmet design have seen a lot of news coverage, the issue has long been of concern to the construction industry. According to the U.S. Centers for Disease Control and Prevention, the greatest number of traumatic brain injuries occur on construction sites. Recent data further show that such injuries account for one-quarter of construction-related fatalities. This statistic has motivated ongoing research into head-protection devices and to the design and development of more effective hard hats. Although improvements in the hard hat over the past 100 years have provided construction workers much better head protection than the hard-boiled hat, there remains room for further improvement.

Selected Bibliography

Carpenter, M. 2019. A symbol of toughness turns 100. *New York Times,* October 1, pp. B1, B5.

Freeland, L. 2019. Hard hats turn (at least) 100. *Elevator World.* https://www.elevatorworld.com/hard-hats-turn-at-least-100/1

Rosenberg, B., and C. Levenstein. 2010. Social factors in occupational health: A history of hard hats. *New Solutions* 20(2):239–249. doi: 10.2190/NS.20.2.h.

Tenner, E. 2003. Hardheaded logic. *Invention & Technology,* Summer, pp. 34-43.

U.S. Bureau of Reclamation. 2015. The story of Hoover Dam: High scalers. Accessed March 15, 2020. https://www.usbr.gov/lc/hooverdam/history/essays/hscaler.html

Arts Lab

Depicting a Fragmented World

Mosaics provide a window into the Anthropocene.

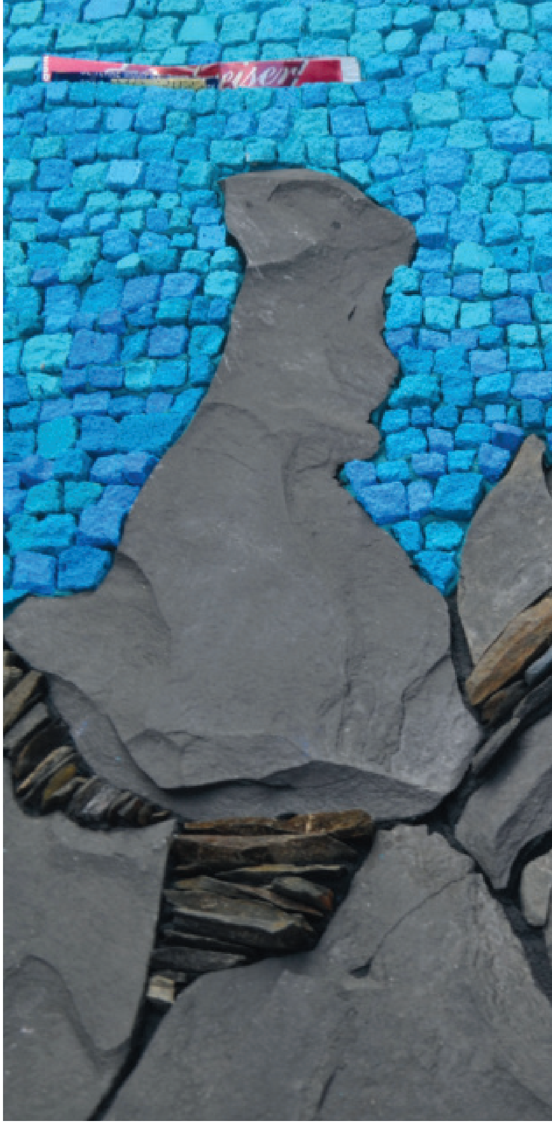
Julie Sperling

I remember exactly when it started. I was going through the daily batch of news clippings at work when I clicked on an article about how some climate trend or other was much worse than scientists had anticipated. That I can't recall the exact trend is quite telling. I half-heartedly skimmed the article, eyes glazing over, thinking, "Yeah, yeah, I know it's bad . . ." And then I stopped. Here I was, an environmental policy analyst with Environment and Climate Change Canada (the Canadian equivalent of the U.S. Environmental Protection Agency)—someone whose day job centered on being informed about and invested in these topics—and I had reached the saturated, eyes-glazed-over point with the seemingly endless stream of articles about environmental collapse. And if I had reached that point, how were other people supposed to care?

As fortune would have it, though I was a bureaucrat by day, I was also a budding mosaic artist by night, and at that point in time I was searching for the big "Why?" that would be the focus of my art. The timing couldn't have been better, and right then and there I decided I would make art about climate change as a way to help myself and others engage with the subject. And thus my climate change series "Fiddling While Rome Burns" was born. Since that day six years ago, my art has focused exclusively on climate change and, more recently, the Anthropocene—the epoch defined by the human-altered environment.

As it turns out, what began as a gut feeling and a personal reaction is backed by a significant body of research debunking the *deficit model* of science communication, a one-way approach in which scientists share their research with the "information deficient" public (*see "How Climate Science Can Lead to Action," January–February*). The supposition is that people make poor decisions about climate change or other contentious matters because they just don't know enough. Yet despite ample evidence that simply giving people more facts doesn't work to change their minds, we continue to try it, believing that if we could just explain climate change or other issues better, or if we could find that one killer fact, we'd somehow convince them to care. As a bureaucrat (yes, I'm still leading a double life all these years later), I get it. Trying to sell something tangible such as an information campaign to my bosses would be infinitely easier than explaining that we need to invest in art in order to reach people on an emotional level.

Art is subjective, messy, and unpredictable. But it's also an essential part of the dialogue surrounding the climate emergency and the overall collapse of our planetary life support systems. Research has shown that engaging with people based on shared values and experiences can be far more productive than the give-them-more-facts approach. Art, given its subjectivity, can provide a platform for these more tailored, intimate conversations, meeting people where they are and gently nudging them forward. And artists of all mediums around the world are increasingly taking up this challenge; we each approach the topic in a different way.

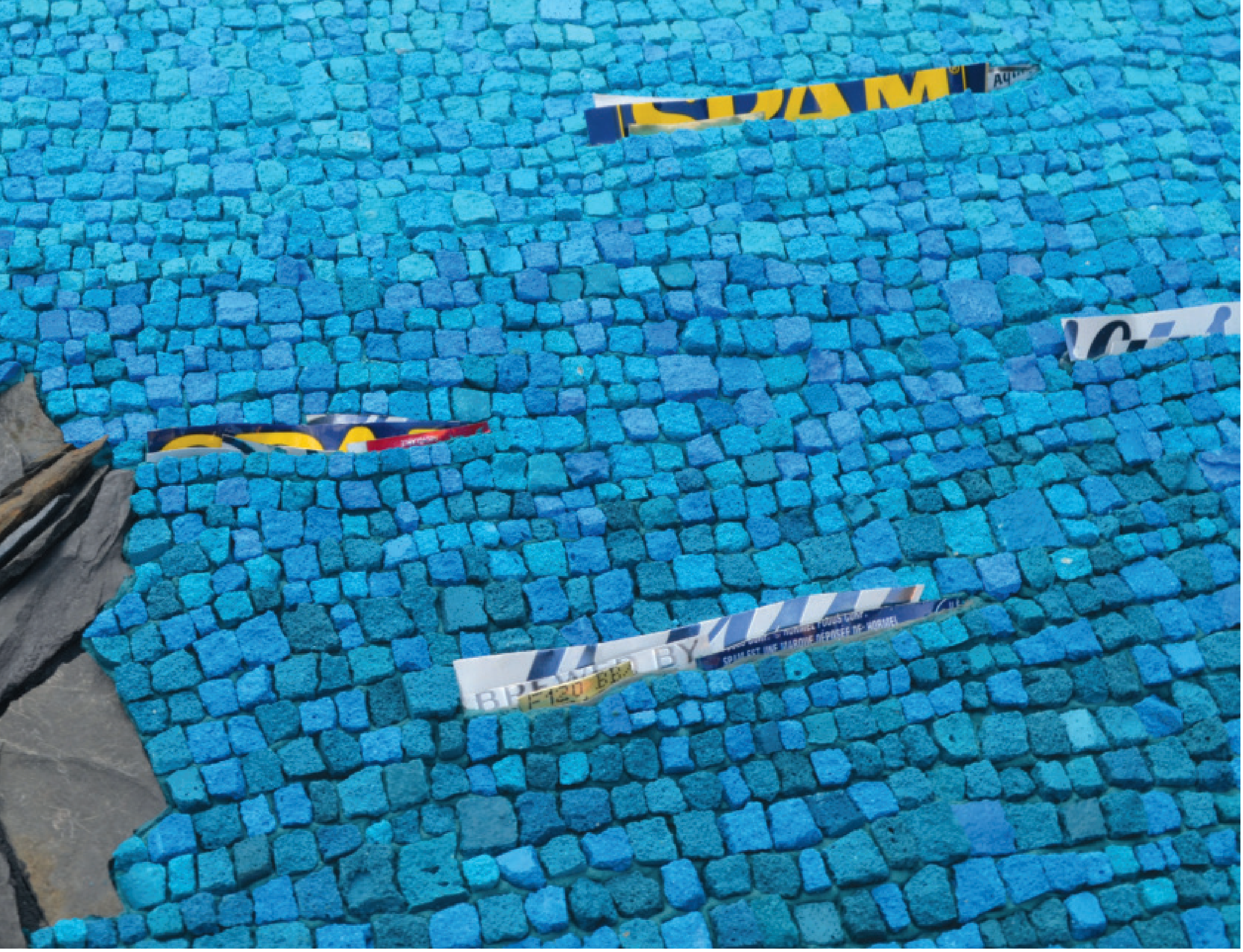


Personally, I use the medium of mosaic to talk about these big issues. I am, of course, biased, but I think mosaic has a few tricks up its sleeve that make it a very powerful medium with which to explore climate change and the Anthropocene. One of mosaic's biggest strengths is that it is so materials-driven. My material of choice is stone, but I'll use almost any material that will help me tell my story, including bullet casings, bones, plastic bags and utensils, e-waste, my old boots, and so much more. If I can cut it, it's fair game.

Beyond the visual aspects of a material (including its color, texture, and reflectivity), the most important part for me is the meaning behind it and what I can say with any given material. I work with coal and shale a lot, making beautiful things out of "dirty" materials. I use them for their direct meanings—for instance, using coal in a mosaic about black carbon—but I also

---

Julie Sperling is a mosaic artist based in Kitchener, Ontario. Her work explores the intersection of art, the environment, science, and policy. Website: http://www.sperlingmosaics.com



Julie Sperling

Everything We Touch **shows ripples of Spam and Budweiser cans floating down to the depths of the Mariana Trench, demonstrating that no place on Earth is beyond the reach of humanity.**

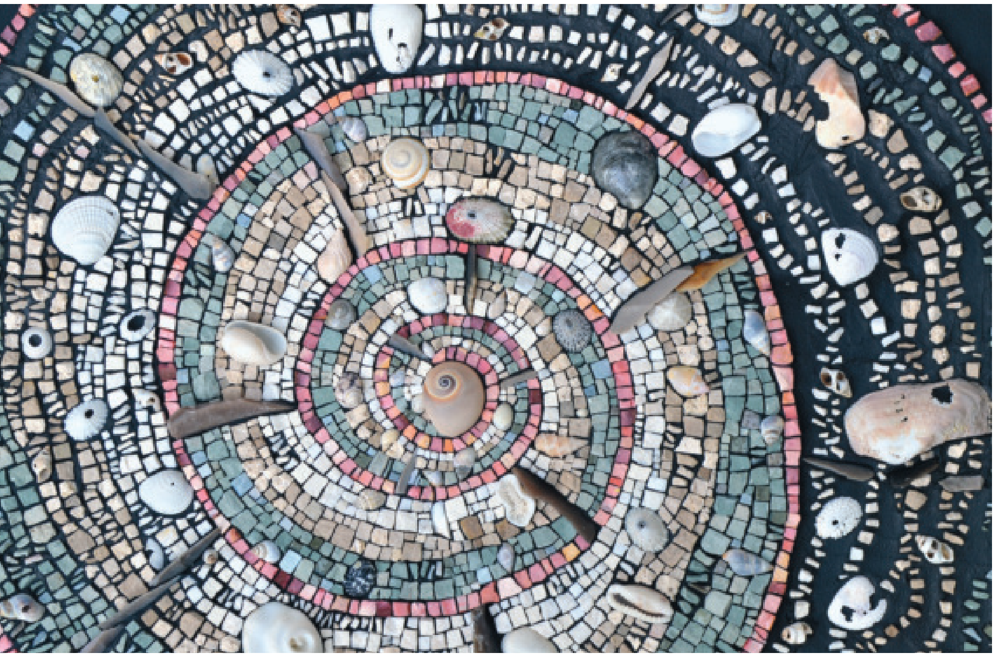
use them as proxies for the fossil fuel industry and greenhouse gas emissions more generally. I have also used shells that I submitted to my own homemade ocean acidification simulation wherein I stick them in vinegar to degrade them, and I have made an entire mosaic out of just white plastic to highlight the problem of ocean plastic pollution. I used cans of Budweiser and Spam in another piece inspired by the trash that the National Oceanic and Atmospheric Administration found in the Mariana Trench (*see image above*). Using these materials allows viewers to get up close and personal with substances they may not encounter in their everyday lives (such as coal) or to see ordinary materials in a different light (the shells, plastic, or beer cans) and connect them with bigger concepts and problems.

Another powerful tool that I employ in my work is what mosaicists call *andamento*, which refers to the lines, movement, and flow of a mosaic. It's how we put all those hundreds and thousands of pieces together to tell a story. The ancient Romans set out rules for the composition of a mosaic, but contemporary mosaicists take these classical rules and bend them, break them, and sometimes invent new ones altogether. Composing a clear narrative in any given mosaic requires a dance between the materials and the andamento.

In depicting ocean acidification, I created the image of a degrading shell, where the andamento in the middle was very classical, tight, and whole (*see image at top of page 156*). Then I started introducing little glitches in the lines—pieces just slightly out of place—that become bigger and more frequent as the spiral moves outward, until at the very edge it is a very loose, somewhat chaotic andamento. This message is reinforced by the shells themselves, which are also intact in the center, and, like the andamento, become increasingly degraded moving outward, with the ones on the edge having sat the longest in the vinegar.

Another of my mosaics is inspired by reports I read about the global state of soil (*see image at bottom of page 156*). I wanted to convey just how thin, vulnerable, and valuable our layer of topsoil is. I created a 15-centimeter-thick band of deep rich brown, representing the topsoil. The use of a relatively classical andamento evokes layers of slow accumulation of this precious resource and serves to provide a point of contrast for the degradation that follows in the rest of the mosaic. The materials transition to red brick and terracotta, and the andamento moves away from lines of precisely cut cubes toward a more chaotic, aggressive style made up of larger, more random pieces to mimic cracked, parched earth.

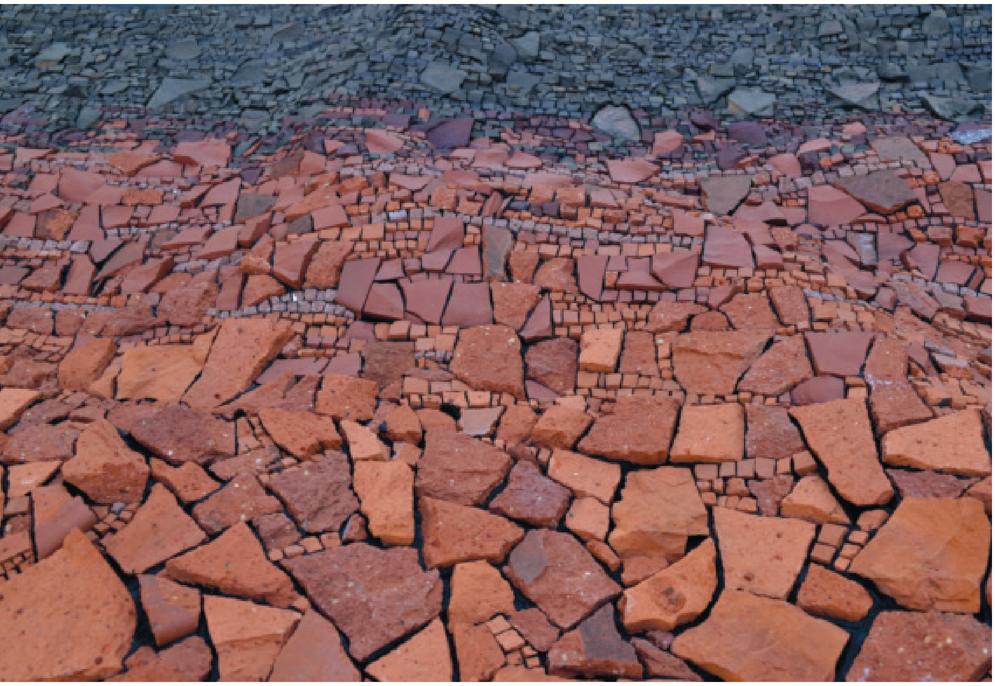
Finally, in telling the story of the mass extinction currently threatening many species, I created an explosion out of a broken ceramic loon against a background of traditional andamento made from concrete foraged from the side of the road (*see image at top of*



Julie Sperling

By depicting a degrading shell using both actual degraded shells and a slowly disintegrating *andamento* (the lines, movement, and flow of mosaic), *Breaking The Hand That Feeds Us* conveys one aspect of the losses caused by ocean acidification.

page 157). Again: two different styles of andamento, two different materials imbued with meaning. By using the official bird of Ontario (my province)—the common loon—I endeavored to make the message hit close to home for people: Loons are not among the animals we tend to associate with extinction, yet their populations have been declining for several decades. The concrete background is a nod to how changes in land use, such as urbanization, are a driving factor in this biological annihilation. And staring straight out from the center of the piece are the loon's haunting red eyes, challenging the viewer to hold its gaze and not look away.



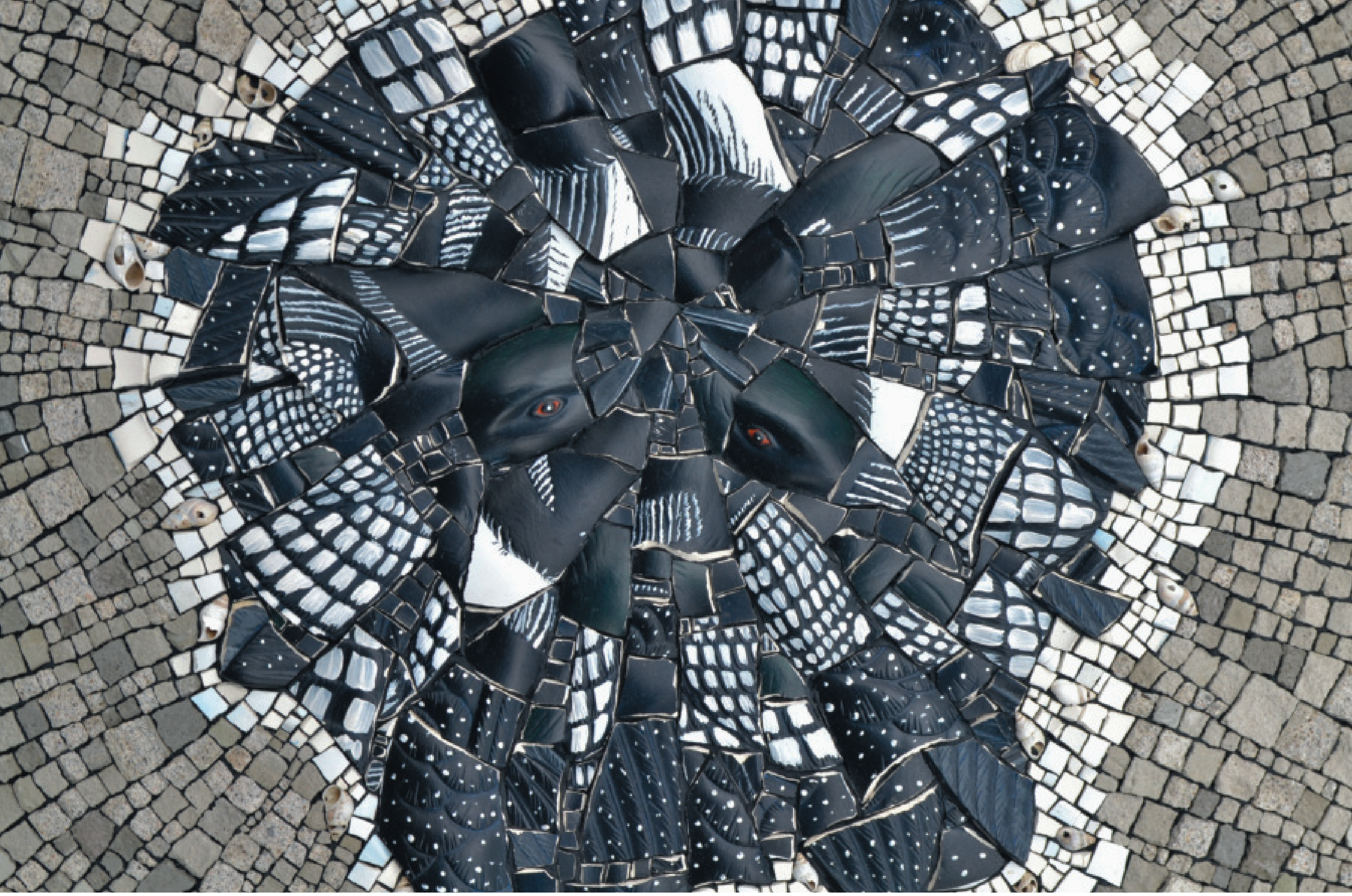
Julie Sperling

The parched, chaotic andamento made of terracotta and red brick in *Inches From Famine*, contrasted with the thin band of fertile soil (seen here in the background), speaks to the rapid loss and degradation of soil occurring worldwide.

One of the strengths of mosaic is that people slow down and spend time with it, because it can be explored on so many levels. Viewers can study its textures and its geographies, they can examine individual pieces of a material, they can follow a line of andamento start to finish, they can take in the entire composition . . . Being able to hold people's interest and curiosity on several timescales provides me with an opportunity to engage and tell a story. More often than not, that story is told in an abstract way. For me, that approach has been the best way to wrap my own artistic brain around these massive and complex issues. It is also a way to communicate that isn't too preachy or didactic (which can be off-putting) and that doesn't offer easy answers, because there are no easy answers to these challenges we're facing. Abstraction allows me to start a dialogue through art and create space for contemplation, questions, and emotion.

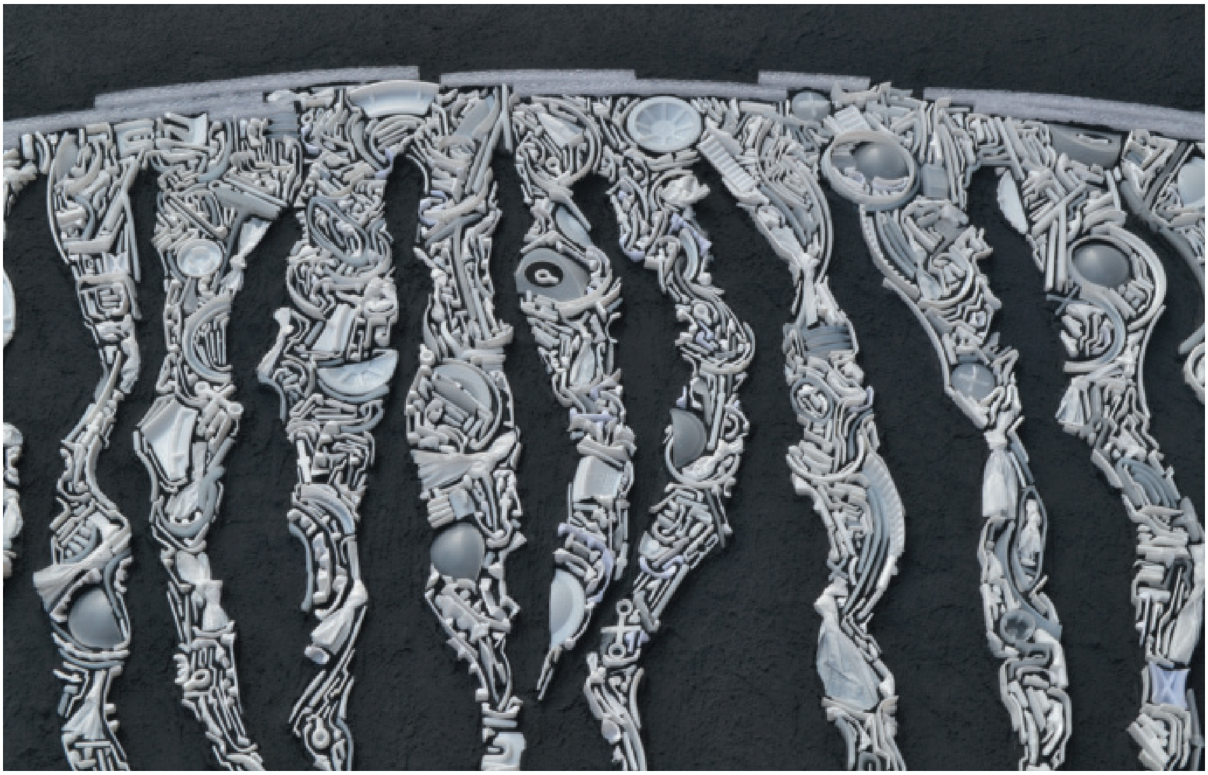
I don't want to alienate the viewer, so I try to walk the line between beauty and destruction. At first glance, I want my work to welcome people, to make them feel comfortable, to encourage them to spend time with my work. But as they are drawn in and begin exploring the mosaics, I want them to realize that something is amiss. That's a beautiful shell, but . . . why are those other shells so corroded? Those are incredibly delicate, lace-like tendrils, but . . . they're made from plastic? (*See image at bottom of page 157.*) That black and white part looks so quilt-like, but it's a jumble of bird, and it won't stop looking at me. As an artist, I think that place of gentle discomfort can be a very productive one for the viewer.

Though I didn't know it when I set out on this path, I have come to understand just how powerful mosaic can be as a medium for depicting complex global challenges. I started this body of work to fight disinterest and apathy, and over the years I've had the pleasure of hearing from people about how my art has expanded their awareness or changed their actions. However, all that quiet time in my studio, slowly, painstakingly putting each mosaic together piece by piece, has also ended up creating space for me to contemplate and wrestle with these issues. In working to engage others, I have also managed to re-engage myself. ■



Julie Sperling

Haunting red eyes challenge the viewer in the middle of an exploding ceramic loon set against an expanse of cement in *In The Red*, a mosaic that confronts the staggering loss of biodiversity driven by human activities (*above*). Inspired by numerous accounts of whales washing up on shores around the world with stomachs full of plastic, *In The Belly Of The Whale* is composed of delicate ribbons of plastic arranged in an entirely new style of andamento and hanging from the inside of a belly-up whale (*below*).



Julie Sperling

Is There a Better Way to Control Room Temperature?

Office occupants often complain of being too hot or too cold, but new uses of technology could help defuse the thermostat wars.

Da Li, Carol Menassa, and Vineet Kamat

In any office, home, or shared space, there's almost always someone who's too cold, someone who's too hot, and someone who doesn't know what the fuss around the thermostat is all about.

Even though the variables that determine a comfortable temperature are all too human, building environments typically use static temperatures—a range of 20 to 23.8 degrees Celsius (68.5 to 75 degrees Fahrenheit) in winter and 23.8 to 26.9 (75 to 80.5) in summer—to program and run office heating, ventilation, and air conditioning (HVAC) systems. As a result, people often feel too hot or too cold, despite how much energy heating and cooling systems expend in an effort to create comfort.

Regulating an Artificial Environment

In the United States and worldwide, HVAC systems account for about 50 percent of the total energy required to operate commercial and residential buildings. Commercial buildings alone account for 22 percent of the United States' national energy consumption. Yet this high energy use rarely results in its goal of universal satisfaction with a building's temperature.

Because HVAC systems are programmed to always deliver predetermined levels of heating or cooling, they do not take into account, or adjust for, human data or personal comfort preferences. Further, because these systems do not adjust for variable factors—such as heat from direct sunlight—in a space, the air temperature is not uniform and people can experience varied thermal sensations.

Performance, Health, and Comfort

People would be more comfortable if building HVAC systems could respond in real time to their varying comfort levels and their fluctuations throughout the day. A person's satisfaction with their environment, and specifically their thermal comfort level, has a direct effect on their health, well-being, and performance.

And, considering that people in the United States and Canada spend an average of 90 percent of their time indoors in the summer and 97 percent indoors during the winter, this relationship can have significant, far-reaching effects. Employee performance in indoor offices can be greatly affected by the environment's perceived thermal condition. An employee who is personally comfortable in their thermal environment is likely to have a reduced number of complaints, decreased absenteeism, increased productivity, and improved motivation.

An uncomfortable thermal environment, however, leads to low job satisfaction, negatively impacts job performance, decreases self-estimated performance, and may cause difficulties concentrating. High room temperatures can lead to increased reports of symptoms of *sick building syndrome* (a feeling of ill health that occurs in the occupants of a building, such as eye, nose, and throat irritation) as well as increased mental workload to complete cognitive tasks.

And although factors such as motivation can offset a negative thermal environment's effect on task performance, dealing with that thermal stress can still deplete a person's overall neural resources. In the long term, that continuous high mental workload can be detrimental to overall health. Controlling the thermal environment through the HVAC system by adjusting thermostat set points is one of the simplest ways to achieve an optimal workplace environment.

Different Comfort Levels

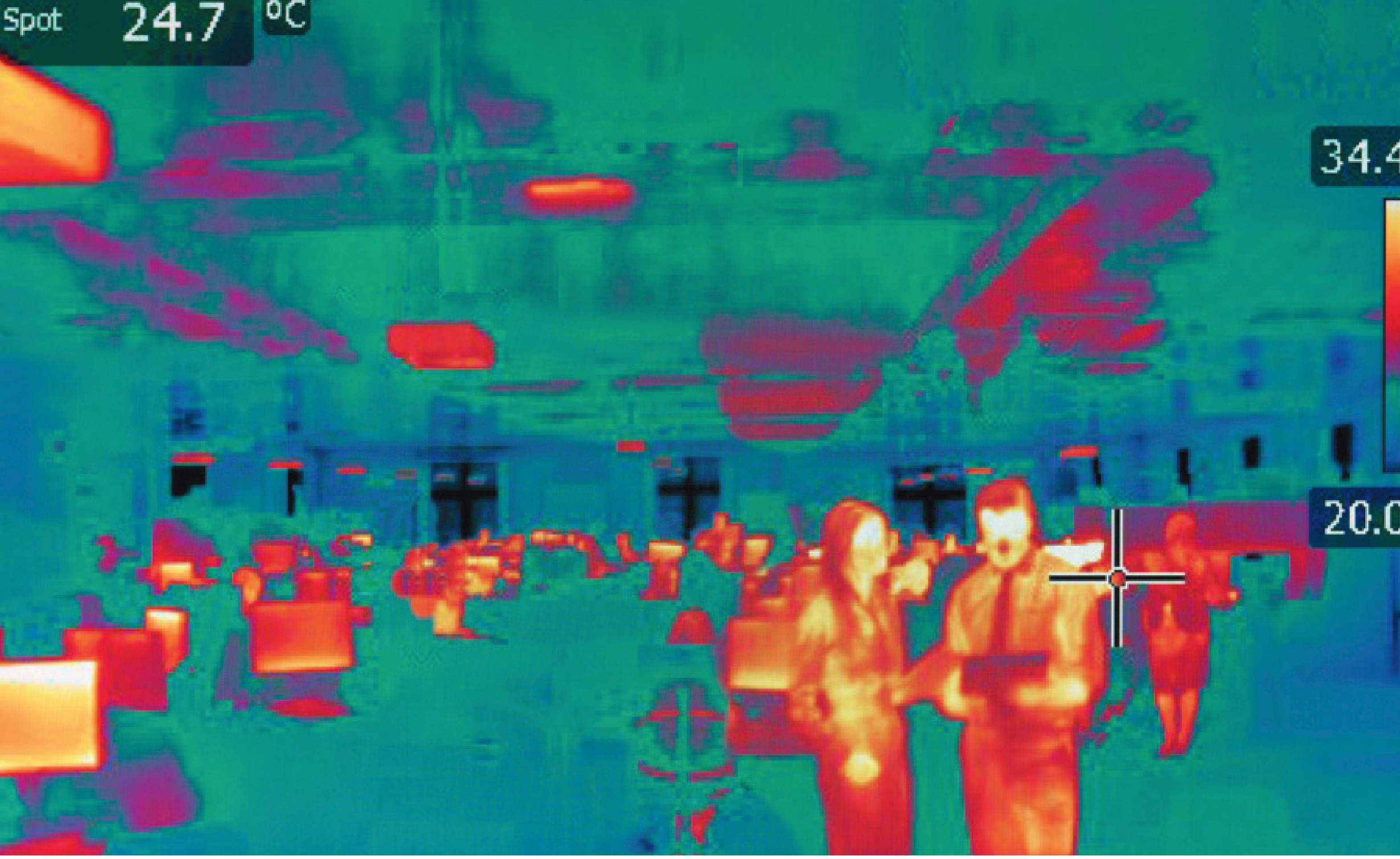
Most often, building owners find out how well their heating and cooling systems are operating by asking how comfortable the occupants are. However, everyone has an ideal temperature that may change at any given time based on all sorts of factors, including their age, gender, physical activity level, apparel, and even current stress level. These dif-

QUICK TAKE

Buildings expend considerable energy heating and cooling offices to predetermined, static temperatures, but many people still feel uncomfortably cold or hot at their jobs.

A body's physiological responses (such as skin temperature, respiration, and heart rate) are correlated to its comfort level and surrounding thermal sensations.

People working in an environment warmer than their comfort level must devote more mental resources to complete a task than when in a comfortable thermal environment.



Monty Rakusen/Image Source/Alamy Stock Photo

Thermal imaging is used to create a *thermogram* that shows patterns of heat, with white and yellow usually representing warmer temperatures and blue and black representing cooler temperatures. In these heat patterns, the skin temperature of building occupants can be used to monitor and adjust building temperature. However, not all relevant factors are addressed by skin temperature data: Women generally have a slightly higher skin temperature and larger variations in temperature than men; skin moisture level, or sweat, can affect temperature measurement accuracy; and clothing insulation and activity level can vary between occupants.

fering comfort levels create a complex problem: how to determine the most comfortable thermal environment for the greatest number of people, and how to successfully regulate it.

The predicted mean vote (PMV) model, created by Danish environmental engineer and expert in thermal comfort Povl Ole Fanger, assesses thermal comfort using four environmental factors (air temperature, mean radiant temperature, air velocity, and relative humidity) and two human factors (metabolic rate and clothing insulation). The PMV model has become an international standard and is used to evaluate occupant indoor thermal comfort on a seven-point thermal sensation scale, with -3 being cold, 0 being neutral, and +3 being hot.

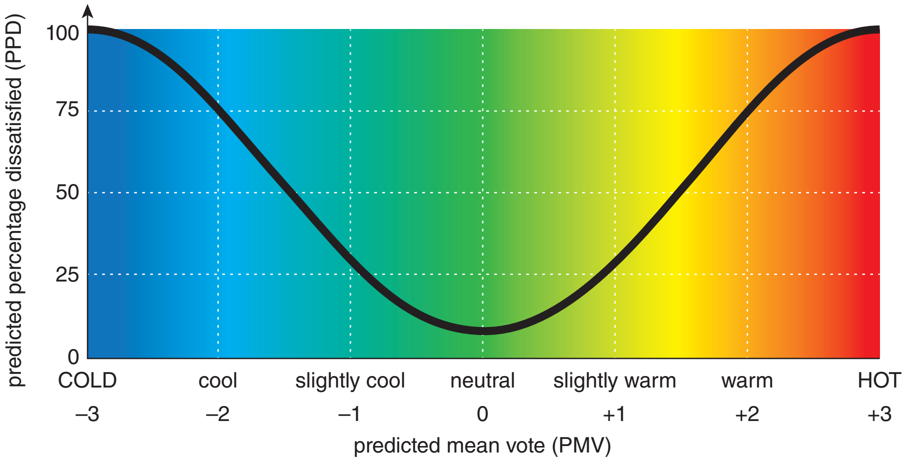
This model doesn't account for all factors, however, and its major drawback is that human factors are assumed to be the same across all people—it doesn't take personal variations into consideration. Even when exposed to the same indoor environment and workload, people may still have diverse sensations and preferences because of their own personal factors. Time of day and seasons influence this comfort level as well: People entering a cool room in the summer may initially feel comfortable but end up feeling too cold after a while.

Assessing Thermal Comfort

Improving a thermal environment first requires an understanding of both the current situation and relevant information on the occupants of the space to determine how it could be improved, which means occupants' thermal comfort must be accurately assessed. There are two main ways to achieve this measurement: occupant self-reports and comfort assessments through human physiological responses.

Some researchers have proposed asking occupants to self-report their comfort level or vote on what they feel the temperature should be. Using a phone app or website, building occupants select whether they're too hot or too cold, and what would make them more comfortable. An algorithm then analyzes the answers and calculates a temperature estimated to be the most acceptable to most people. However, for it to work well, self-reporting requires near-constant input from people who are supposed to be working—and it still doesn't factor in whether someone who is uncomfortable could help themselves by putting on or taking off a sweater. It also doesn't take into account how people's bodies experience temperature, which is closely tied to how cool or warm they prefer their environment to be.

Another option to assess thermal comfort is to measure physiological responses from human bodies. A body's physiological responses—such as skin temperature, respiration, and heart rate—are correlated to its comfort level and surrounding thermal sensations. As a result, it's possible to gather occupants' comfort status without inconveniently requesting self-reports or votes. Among these physiological responses, skin temperature is an effective predictor of thermal comfort.



Barbara Aulicino

The predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) indices were created to measure thermal comfort levels and limits in an indoor environment. These indices were added to the American National Standards Institute (ANSI) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55-2017, which establishes acceptable ranges and sets requirements for indoor thermal conditions.

Skin temperature can be measured using wearable devices, usually through either direct skin contact or infrared thermometers placed very close to the skin. Direct skin contact measurements are collected with *contact thermocouples*. These are accurate and easy to use, but can be intrusive because they must always be in contact with the person's skin. Because temperature gradients on the hand, wrist, and upper arm are good indicators of thermal sensation, contact thermocouples are often placed in wristbands. *Infrared thermometers* are more difficult to use because they must be placed very close to the skin to obtain accurate readings, which means that although good choices exist, such as those built into eyeglass frames, there are fewer less-intrusive options.

In previous research, our group used a combination of these devices by placing multiple temperature sensors around an office, having occupants wear wristbands that monitored skin temperature and heart rate, and requesting occupants to self-report their comfort level. We found that adding data about how people's bodies were reacting made the algorithm more accurate at calculating the room temperature at which people occupying a given space would feel most comfortable. However, this combination of data-gathering techniques still suffered from the previously mentioned challenges, which leads to a third option: thermal cameras.

Thermal cameras create images using infrared radiation and can be used to remotely sense occupant body temperature. They have a longer and more flexible working range but generally are less accurate than contact thermocouples and infrared thermometers. They also provide a full-frame image of thermographic measurements that can be used to determine temperature readings at each pixel location.

Measuring people's comfort in an environment and then automating HVAC systems to adjust as needed would be groundbreaking for many high-occupancy spaces.

Although it can be helpful to incorporate additional information, such as heart rate and activity level, from other data collection methods into the comfort prediction model to improve its accuracy, skin temperature is often the most effective and easy-to-use quantitative data.

Data from Occupant Bodies

The human body maintains its core temperature at around 37 degrees Celsius (98.6 degrees Fahrenheit) through thermoregulatory control of blood flow to the skin's surface. Because skin temperature is directly affected by changes in blood flow, these changes in temperature are often used to estimate thermal comfort and sensation.

If an occupant is under heat stress, their body will react: *Vasodilation*—the widening of blood vessels—increases blood flow to the skin's surface, which allows the body to dissipate excess internal heat and increases the skin's temperature. If the same person is too cold in their environment, their body will react: *Vasoconstriction* decreases blood flow to limit heat loss, which results in a cooler skin temperature.

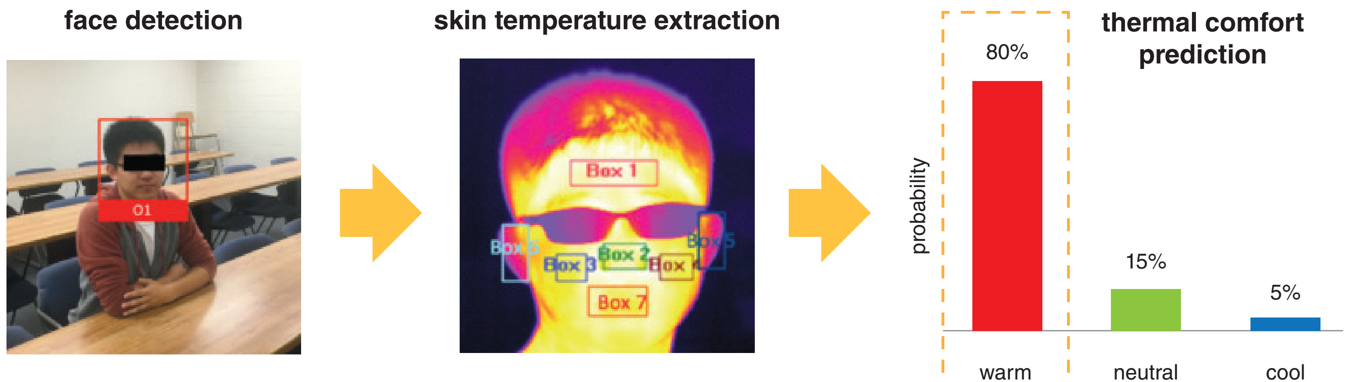
The human face has a higher density of blood vessels than other skin surfaces, which leads to a larger variation in skin temperature in response to changes in the body or environment. This feature makes faces the best location for consistent, noninvasive skin temperature measurement. One experiment found that a variation of 5 degrees Celsius (9 degrees Fahrenheit) in room temperature shows a statistically significant impact on facial skin temperature.

The ideal facial regions to measure skin temperature are those that show the overall largest variations when under thermal stress, which are the ears, nose, and cheeks. Under heat stress, these features have large temperature variations. Under cold stress, ears have the largest variation, followed by the nose, cheeks, and forehead. While a person is in a cooling or heating phase, cheeks show the highest variation.

However, some facial regions, such as the forehead and mouth, are more sensitive to cold stress, which shows that the significant features used to predict a person's thermal comfort may vary under hot and cold conditions. In addition to being sensitive to temperature changes, faces are ideal for remote monitoring because they often are not covered by clothing, so any emitted infrared energy can be directly measured using a thermal camera. Also, algorithms can detect human faces well, and can be written to easily locate specific regions of interest—such as the ears, nose, and cheeks—within images for data analysis.

Automating Temperature Changes

To accurately collect and process the data, each data point first must be detected correctly. A machine learning–based object detection algorithm detects the existence of certain features—such as edges or changes in texture—in an image to identify first faces and then specific facial features.



Da Li et al.

Face detection software is coupled with thermal cameras to measure a person's skin temperature and evaluate whether they are too warm, too cold, or comfortable in their thermal environment. Once detected, the facial image is divided into specific regions of interest. Although faces provide the most consistent and least-intrusive skin temperature readings, one concern is ensuring consistency, as some facial features may not always be visible because of, say, hairstyles that cover the forehead, or personal clothing, such as hats or eyeglasses.

Once faces have been correctly identified, facial skin temperature measurements are processed. Thermal cameras capture images and temperature readings of occupant faces. A set of algorithms then divides the images into different facial regions, extracts temperature readings based on the regions of interest, discards the images to alleviate privacy concerns, processes the data, and determines the best thermal change to stay within statistically acceptable comfort levels for most people.

Comfort prediction models then take what are called *linear regression models*, which use skin temperature as the independent variable and the overall thermal sensation as the dependent variable. These data are combined with machine-learning methods that complete the regression and classification analysis on the data; common methods used to classify thermal comfort are *support vector machines* (which classify new data based on learned categories) and *decision trees* (which guide the response path through a framework of possible outcomes based on the input).

An HVAC control framework then uses these algorithms, machine-learning methods, and human data to set the building temperature controls. This process is called a *human-in-the-loop system*, meaning it requires both human input and machine intelligence to create the machine-learning model. In this specific instance, the human input is the physiological responses to thermal sensations and behavioral data, then the system's allowance for human-based adjustments to the HVAC system.

A *collective decision algorithm* determines the most optimal temperature set point by maximizing the PMV index, or group comfort, score. Then an *ensemble classification algorithm* called Random Forest is used to produce better prediction results of classifying objects by averaging a large collection of decision trees. These personalized prediction models only need to be trained once and then will continuously predict each occupant's comfort level. A control script then continually executes the decision algorithm to connect the data to the physical HVAC system. All of this culminates in an automated, user-centric, data-driven system that will consistently monitor occupant skin temperature and adjust the environment's temperature to ensure each person is as comfortable as possible.

This method is most effective in multi-occupancy spaces, such as open-plan offices, meeting rooms, and theaters. It can accommodate, and account for, differences in temperature between people in different areas of a room, whether they are standing, sitting, or moving around. And it can adjust on the fly without requiring active human feedback. In tests of this system, people complained less about feeling uncomfortably warm or cold, and occupant thermal comfort preference was predicted with 85 percent accuracy by using facial skin temperature measurements.

Measuring how comfortable people are in an environment and then automating HVAC systems to adjust as needed would be groundbreaking for many high-occupancy spaces. Especially exciting would be the successful integration of remote-sensing temperature measurements, which do not place any constraints on occupants' activities. Integrating a type of occupant registration that would track people as they move through the space would further improve real-time data and, thus, occupants' comfort level.

A thermally comfortable environment benefits everyone. Occupants experience improved satisfaction in their environment and overall improved health and well-being. Building owners benefit from occupants' increased motivation and productivity, and they can often reap energy savings from the well-managed HVAC system.

Da Li is an assistant professor in the Glenn Department of Civil Engineering at Clemson University. Carol Menassa is an associate professor, and Vineet Kamat is a professor, both of civil and environmental engineering at the University of Michigan. This article is adapted and extended from a version that appeared in The Conversation, *https://theconversation.com. Email for Li: dli3@clemson.edu*

Bibliography

Centers for Disease Control and Prevention: The National Institute for Occupational Safety and Health (NIOSH). Temperatures and occupancy settings: Indoor environmental quality. September 1, 2015. https://www.cdc.gov/niosh/topics/indoorenv/temperature.html

Li, D., C. C. Menassa, and Vineet R. Kamat. 2018. Non-intrusive interpretation of human thermal comfort through analysis of facial infrared thermography. *Energy and Buildings* 176:246–261.

Parsons, K. 2014. *Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance*. Boca Raton, FL: CRC Press, Inc.

Seppanen, O., W. J. Fisk, and D. Faulkner. 2004. Control of temperature for health and productivity in offices. Lawrence Berkeley National Laboratory Series.

Wang, X., D. Li, C. C. Menassa, and V. R. Kamat. 2019. Investigating the effect of indoor thermal environment on occupants' mental workload and task performance using electroencephalogram. *Building and Environment* 158:120–132.

Gene Editing and the War Against Malaria

Using CRISPR gene drives to breed fitter mosquitoes may prevent a devastating disease.

Ethan Bier and Elliott Sober

Malaria is a tropical illness that blood-feeding mosquitoes spread from person to person. In 2018, approximately 228 million malaria cases emerged, with an estimated 405,000 deaths recorded in the same period. More than half of those deaths were young children. Mosquito nets have limited effectiveness in preventing infection, as do pesticides, and antimalarial drugs also have limited effectiveness in preventing and treating infection (*see figure on page 164*). Compounding this problem is the lack of resources and infrastructure in regions where the risk for malaria is greatest.

Biologists combatting malaria face some choices. They can intervene in human beings, the malaria parasite, or the mosquito. And, instead of traditional methods of fighting malaria, they can use new genetic tools to better reduce the prevalence of the disease among humans, without the toxicity of pesticides and drugs or the challenge of convincing humans to modify their behavior. Now, rather than targeting humans or the malaria parasite, biologists are assessing the use of new tools to edit the genes of malaria-transmitting mosquitoes. The main tool is a *gene drive*: When scientists insert a gene drive into an organism, the organism passes that new gene to all its offspring, and the offspring do the same.

The gene-drive method of altering populations of mosquitoes is a result of the discovery in the past decade of *clustered regularly interspaced short palindromic repeats* (CRISPR)—an immunity system in bacteria that has led to a revolution in precision genetic engineering. A CRISPR gene drive inserted on one chromosome locates a gene sequence on the chromosome next to it. Like a pair of scissors, it "cuts" that sequence and inserts a copy of the pair of "scissors" in the DNA wound. The organism then has two copies of the CRISPR driving gene, one on each of its two chromosomes, so that gene is present in all the ova or sperm that the organism produces. When that organism mates with an individual in which the CRISPR gene is absent, all offspring initially have one copy of the CRISPR gene and one of the wild-type gene that the species had before the CRISPR system was introduced. Then CRISPR goes to work in those offspring, changing them from having just one copy of CRISPR to having two.

CRISPR biologists copy nature, just as plant and animal breeders mimic natural selection when they decide which organisms in a population will be parents of the next generation.

In 2015, Valentino Gantz, a graduate student in the laboratory of one of the authors, Ethan Bier, developed the first CRISPR gene drive for sexually reproducing animals that have different tissue types and organs. Then, in collaboration with the laboratory of Anthony James at the University of California, Irvine, Bier and Gantz developed the first CRISPR gene-drive system for mosquitoes.

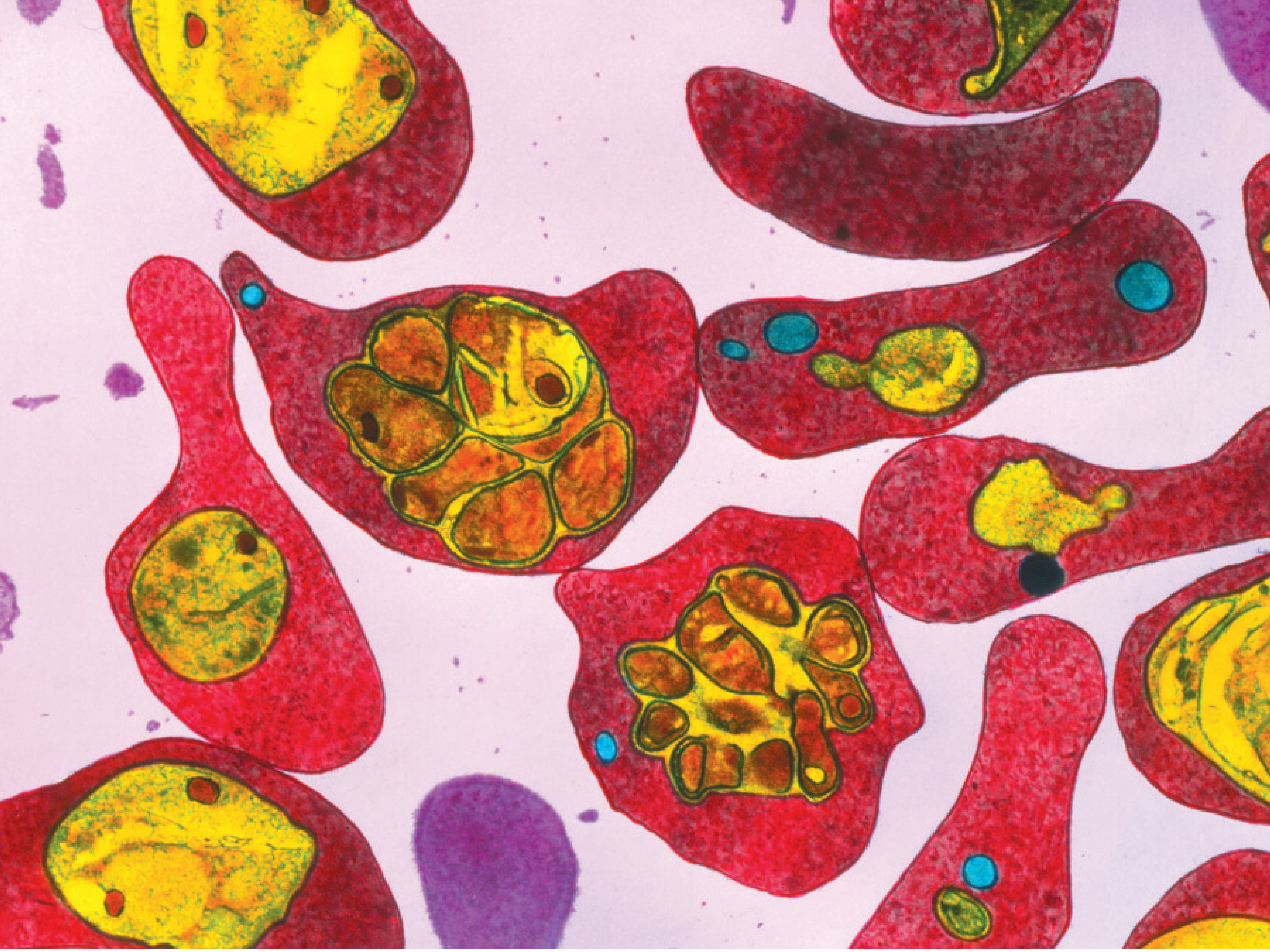
The novelty of CRISPR goes beyond enabling biologists to insert into an organism a new gene that will be passed from one generation to the next. These new genes are designed to circumvent the "laws" of Mendelian genetics and thereby spread in the population, generation after generation, with increased rapidity. These CRISPR-powered self-copying gene drives must be under-

QUICK TAKE

Biologists can use CRISPR, an immunity system in bacteria, to insert genes into an organism. When that organism reproduces, it spreads the altered genes to future generations.

Mathematical models of meiotic drive (a naturally occurring evolutionary process) provide guidance concerning how CRISPR gene drives will do their work.

Two gene-drive strategies may help fight malaria: One suppresses mosquito populations, and the other modifies how the insects house and transmit the malaria parasite.



Dr. Gopal Murti/Science Source

Malaria is a long-standing tropical disease caused by several species of single-celled parasites belonging to the genus *Plasmodium*. The malarial parasite is transmitted from human to human by a few of the hundreds of species of the mosquito genus *Anopheles*. Shown here are infected red blood cells in which the enclaved parasite divides into up to 24 *merozoites*, amoeboids that then burst through the blood cell wall to continue replicating asexually. A breakthrough in blocking transmission to humans by editing a mosquito gene and driving it through local mosquito populations could lead to malaria eradication.

stood in the context of evolutionary and epidemiological processes before the ethics of designing and using them to fight malaria can be adequately considered. One of the authors, Elliott Sober, a philosopher of science at University of Wisconsin–Madison, has published on the evolution side of the story, in collaboration with David Sloan Wilson, a biologist at Binghamton University.

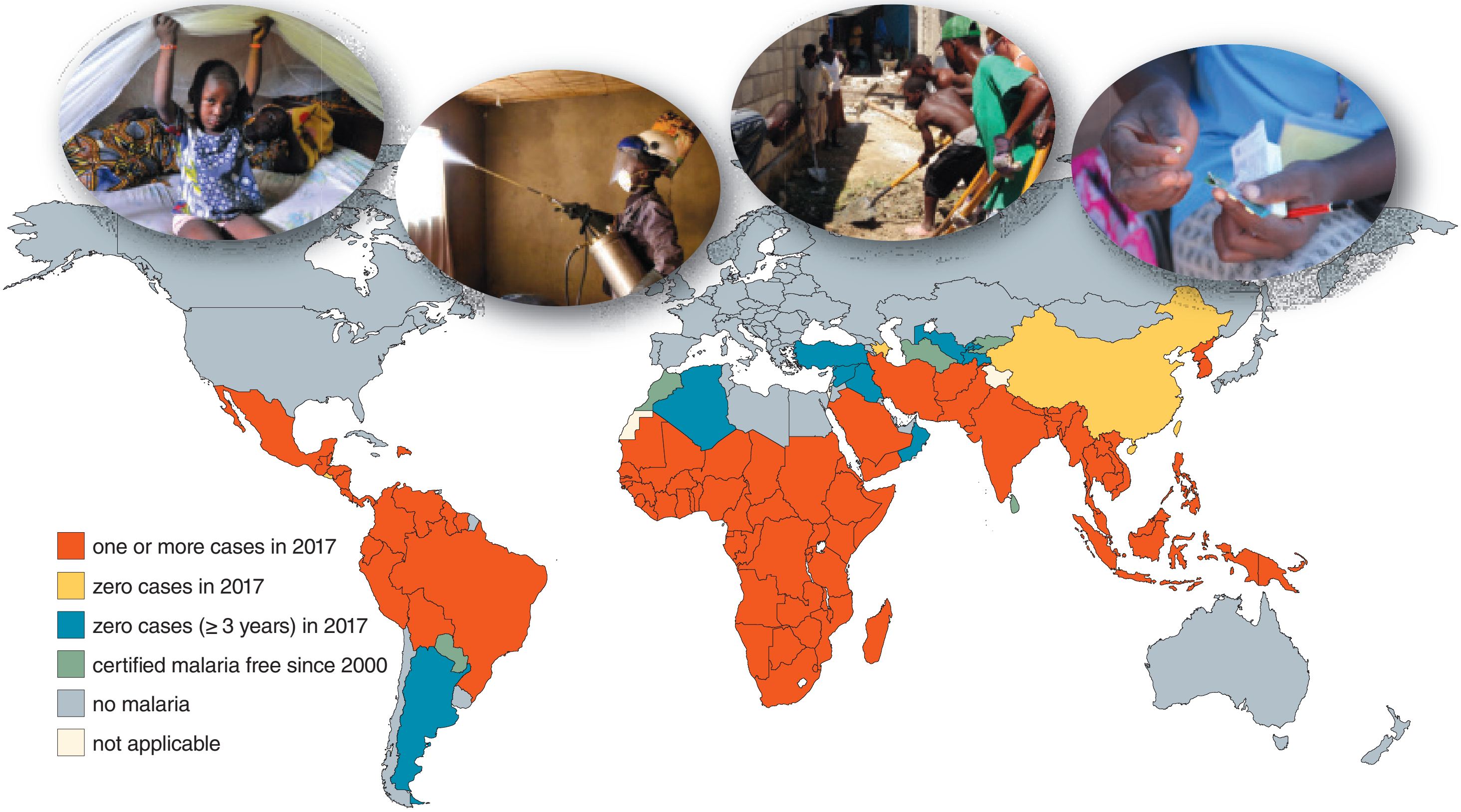
Evolutionary Principles

Although CRISPR gene drives may sound like an exotic technological intervention that has no counterpart in natural processes, they work by means of a process that has affected evolution for as long as organisms have had genes. That process is *meiotic drive*; it was discovered by biologists almost 80 years ago. CRISPR gene drives are engineered meiotic drives. CRISPR biologists copy nature, just as plant and animal breeders mimic natural selection when they decide which organisms in a population will be parents of the next generation.

Understanding CRISPR gene drives requires understanding meiosis in nature. Sexual organisms are *diploid*; they inherit pairs of chromosomes, one from each parent. Each chromosome contains genes arrayed in a line, like beads on a string. The chromosomes in a pair lie side-by-side, so a gene on one chromosome has another gene next to it on the other chromosome. When an organism has two copies of the same gene variant, its genotype at that chromosomal locus is said to be *homozygous*. When the organism has different variants of the gene at a locus, the genotype is *heterozygous*.

Sexual reproduction proceeds by organisms' forming gametes (ova and sperm). Gametes have singleton chromosomes instead of the pairs found in other cells in the body; gametes are *haploid*. Meiosis is the process by which diploid parents form haploid gametes that come together in reproduction to form a diploid offspring.

Gregor Mendel in the 1860s, and the early geneticists whom he inspired around 1900, thought that meiosis was "fair," meaning that heterozygotes have 50 percent of their gametes with one gene and 50 percent with the other (*see figure on page 165*). Geneticists called this even distribution "the law of independent segregation." This law stood unchallenged until 1942, when


one or more cases in 2017
zero cases in 2017
zero cases (≥ 3 years) in 2017
certified malaria free since 2000
no malaria
not applicable

Map data from World Malaria Report 2018/WHO; photos: Jane Silcock, Brant Stewart/RTI, Laura Newman/U.S. Government Works; International Disaster Volunteers/CC-BY-2.0

Today, malaria still affects many regions in the world, as shown in this 2019 map. Bed netting (*far left image*) and pesticide applications (*second image from left*) are used to prevent transmission by mosquitoes, but success has been limited. A more effective way to reduce malaria incidence is to cover standing water, where mosquito larvae thrive, or to dig and maintain ditches and canals that move the water away (*second image from right*). Antimalarial drugs are administered to prevent, as well as treat, malaria, but they have limited effectiveness (*far right image*). Long-term antimalarial drug use can result in neurotoxic, psychiatric, and other adverse effects. Drug resistance is common.

Barbara McClintock discovered a gene in maize that breaks the law. Such segregator distorter genes garner more than 50 percent representation in the set of gametes that a heterozygote produces. These "driving genes" have since been discovered in multiple plant and animal species.

If driving gene D and wild-type gene W are in the population, then one can discover that D is a driving gene by looking at the gametes that heterozygotes produce. But this situation presents a puzzle. Why do copies of W remain in the population even though the W gene competes so poorly with the D gene? The presence of W suggests that a second, countervailing cause of trait frequency must be at work.

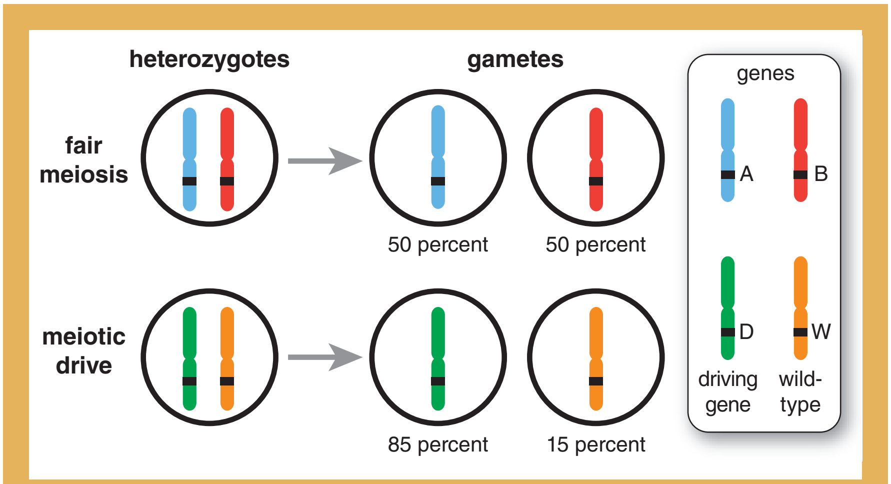
Discerning this second cause was part of the 1950s discovery of a house mouse driving gene. DW heterozygotes produce 85 percent D gametes and 15 percent W gametes. Male DD homozygotes are sterile, however, whereas WW and DW mice are fertile. Consequently, in heterozygotes, D outcompetes W, but WW homozygotes outcompete DD homozygotes (*see sidebar on page 167*). Selection within heterozygote individuals therefore coexists with selection between homozygote individuals. Gene D wins the first competition but loses the second, with the result that neither D nor W achieves 100 percent representation in the population. The takeaway lesson is that understanding the evolution of a driving gene involves two considerations: how the gene works in DW heterozygotes, and how DD and WW homozygotes compare with each other.

Gene-Editing Targets

In the war against malaria, biologists can consider three possible targets: humans, mosquitoes, and the malaria parasite. Intervention in humans is limited to developing effective vaccines and antimalarial drugs, but vaccine development has proven challenging. To understand why, consider two possible vaccine types. The first type is the familiar protective vaccine that inoculates the vaccinated person against infection. The second, more promising type of vaccine blocks transmission of malarial parasites to others. This type of vaccine is called *altruistic* because it protects others, not the person who is vaccinated. Protective vaccines have been more difficult to develop because they act on parasite stages active in humans, whereas transmission-blocking agents counteract parasite stages present in the mosquito.

Why is it easier to take out the parasite in mosquitoes than in humans? Human beings, like all vertebrates, have two immune systems: the sophisticated and highly specific adaptive immune system, and a more basic innate system. Mosquitoes have only the simpler innate immune system. The malaria parasite has evolved the ability to live successfully in both hosts, but the evolutionary challenge of coping with the two immune systems was more severe than the challenge of coping with just the one. Consequently, the parasite now has numerous flexible devices for defending itself against the human immune system, but fewer and less flexible devices for defending against the simpler, less challenging mosquito immune system.

Another consideration strengthens this conclusion. Producing a vaccine for human beings that protects them against parasites that have cell nuclei (*eukaryotes*) has always been problematic. Eukaryote parasites, malaria included, are much more complex than viruses and bacteria. They have evolved many adaptations to undermine a host's immunity. Developing a vaccine that renders human beings immune from malaria has therefore proven challenging.



Barbara Aulicino

Long before molecular biology and CRISPR gene-editing technology existed, biologists detected genes that violate Gregor Mendel's "law" of *independent segregation*, otherwise known as *fair meiosis*. Under Mendelian fair meiosis, individuals that have a pair of chromosomes with gene A on one and gene B on the other produce a set of gametes (ova or sperm) in which half have A and half have B. By contrast, under the force of *segregation distortion*, or *meiotic drive*, individuals that have the driving gene D on one chromosome and have the wild-type gene W on the other will produce a set of gametes in which more than half have D.

Alternatively, why not genetically modify the malaria parasite itself? In principle, this strategy sounds sensible, but in practice scientists have been unable to determine how genetic information can be inserted into the parasite. One possibility would be to insert a virus that would either kill the parasite, or make it less virulent. Unfortunately, no such virus has been described in the literature. And even if such a virus could be found, what fraction of parasites would it infect, and would the parasite respond by simply latching onto another molecule produced by the host mosquito?

The bottom line, therefore, is that modifying mosquitoes is the most plausible strategy for protecting humans.

Option 1: Mosquito Suppression

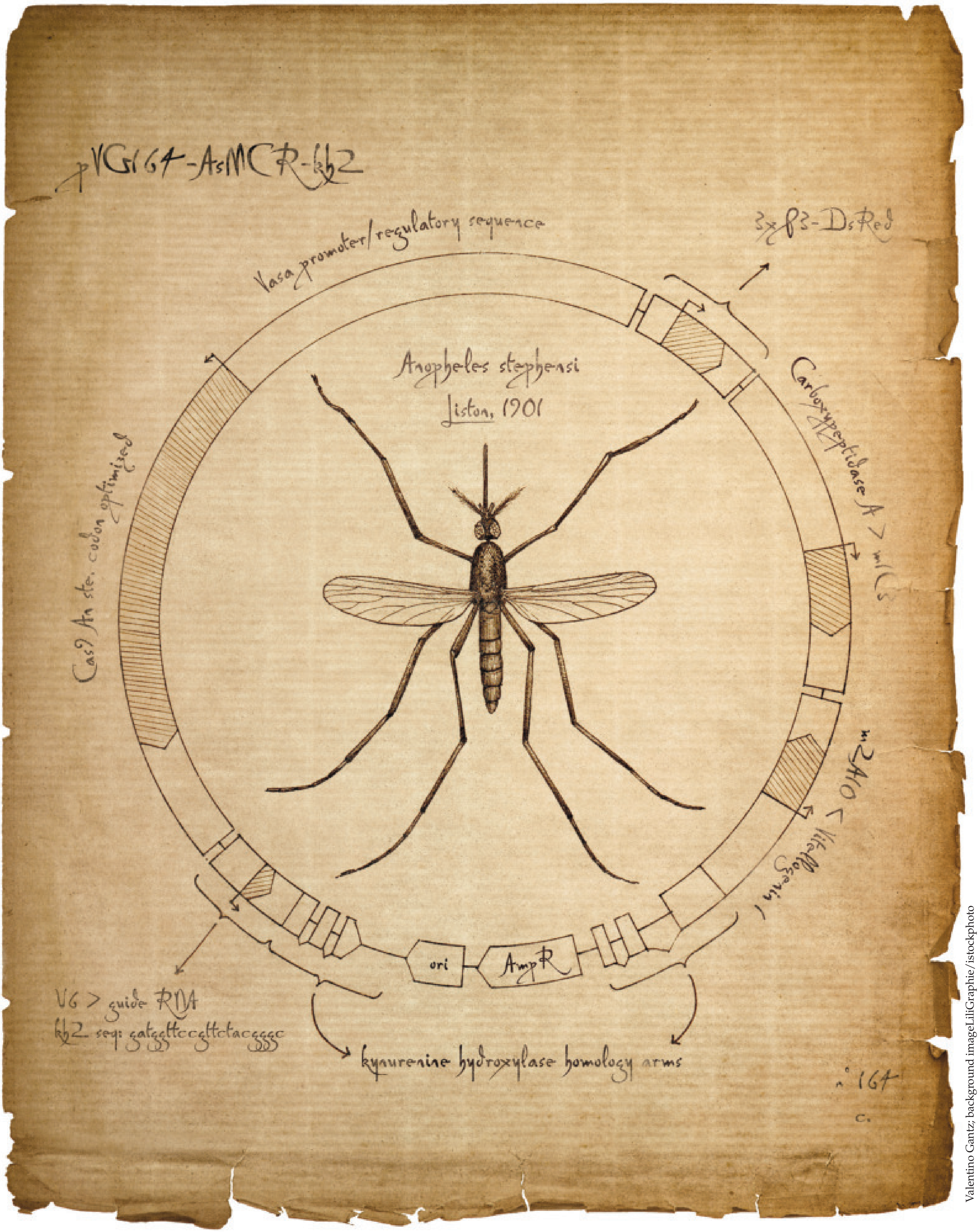
Having settled on mosquitoes as the most feasible organism to genetically modify, scientists face the question of what the gene drive should do. One option is to drive some mosquito species to extinction. In the late 1960s, Christopher Curtis suggested using chromosomal variants to drive a beneficial trait into a population. This idea, although serving as a guiding concept in the field, was technically impracticable. Then, as "selfish" genetic elements came to light, Austin Burt of Imperial College London did the mathematical modeling that pioneered the idea of using them to suppress a population by linking them to a trait that imposes a great fitness cost (often sterility). Sterility drives could be built to exterminate a population of mosquitoes.

Instead of eliminating mosquitoes, scientists have proposed modifying them so that they would be less able to transmit malaria to human beings.

Across the ocean in Southern California, in research spanning the past three decades, Anthony James from the University of California, Irvine (UCI), has considered a different approach. Instead of eliminating mosquitoes, he proposed modifying them so that they would be less able to transmit malaria to human beings.

Different labs around the world have invested in one or the other of these two strategies. The Bill and Melinda Gates Foundation is supporting research at Imperial College London, in Andrea Crisanti's lab, which is pursuing the extinction strategy; at the University of California, San Diego, in the lab of Ethan Bier, coauthor of this article, and in collaboration with Anthony James at UCI, the Tata Foundation and the UCI Malaria Initiative are supporting the modification strategy.

The extinction strategy is well along in its development, although it has not been tried in the wild. In its laboratory, the Imperial College group conducted a small-scale exploratory experiment involving two cages of mosquitoes. Each began with 450 WW mosquitoes and 150 DW individuals (so, counting two genes for each diploid organism, the initial frequency of D was 12.5 percent). No DD homozygotes existed initially, but when the first generation had offspring, DD individuals appeared, and they were sterile. Drive gene D increased in frequency in every generation, and the first cage went extinct after 8 generations, whereas the second went to zero after 12. A generation spans about 14 days. The gene drive at work here did better than the segregation ratio of 85 percent to 15 percent that biologists observe in the house mouse (*see sidebar on page 167*). The Imperial College machinery produces the most extreme segregation ratio possible: 100 percent D to 0 percent W. With this extreme degree of segregation distortion, what evolves is not a balance point in which


pVG164-AsMCR-kh2
Vasa promoter/regulatory sequence
3xP3-DsRed
Anopheles stephensi
Liston, 1901
Carboxypeptidase A > mCh
Cas9 An. ste. codon optimized
m2A10 < Vitellogenin 1
ori
AmpR
VG > guide RNA
kh2 seq: gatggttccgttctacgggc
kynurenine hydroxylase homology arms
n° 164
c.

Valentino Gantz; background imageLiliGraphie/istockphoto

Valentino Gantz, geneticist and fellow countryman of Leonardo da Vinci, created this art about the research to which he contributed. He combined the iconic concept of the *Vitruvian Man* with a malaria-carrying *Anopheline* mosquito circumscribed by a molecular map of the construct used to generate the first CRISPR-based gene drive in mosquitoes.

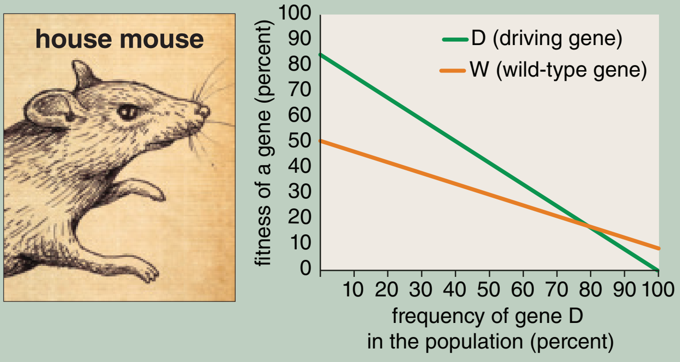
Driving Genes to Three Different Destinations

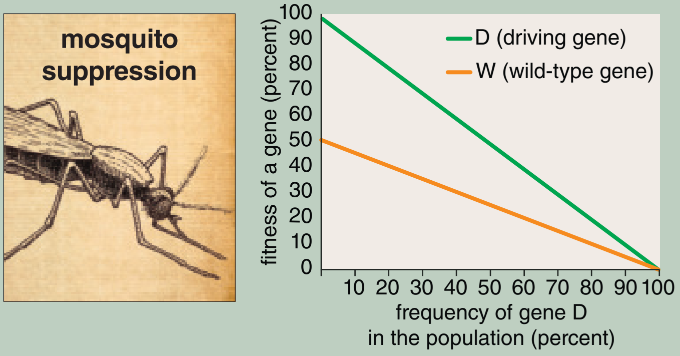
Three plots show what happens in a sexually reproducing species when an "ultraselfish" *driving gene* (D) naturally emerges, or is intentionally introduced by gene editing, and initially outcompetes the original wild-type (W) gene. In all three plots, the *x*-axis represents the percentage of gene D in the population. The *y*-axis represents the fitnesses of genes D and W, meaning the frequency with which the gene variant ends up in a *gamete* (ovum or sperm) produced by a parent who has the variant. Each organism has a pair of genes, one from each parent's gamete, so each offspring is either WW, DW, or DD. In all three plots, the process of natural selection will lead fitter traits to increase in frequency and less fit traits to decline.

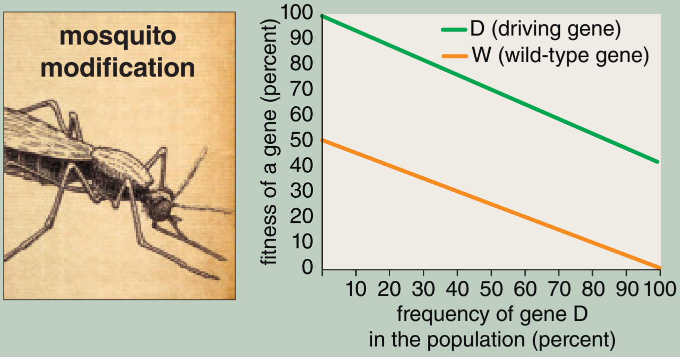
For the house mouse, in which a naturally emerging driving gene D was discovered in 1957 (*first plot*), the lines for gene D and gene W indicate that individuals who were DW produced gametes that were 85 percent D and 15 percent W (*y*-axis). The line for W also indicates that WW individuals had each copy contributing 50 percent to the gametes that those individuals produced. The line for D indicates that DD individuals made no gametes at all, because they were sterile. The net result is that the population evolved to 85 percent D (*x*-axis). This "balance point" at which D and W are both stably maintained in the population is where the D and W lines cross.

In contrast to this balance point of 85 percent D and 15 percent W, the second plot, representing a CRISPR gene drive that might be introduced to suppress malaria-transmitting mosquitoes, shows the extreme case in which DW individuals produce gametes that are 100 percent D and 0 percent W, with DD offspring being sterile. The population evolves to 100 percent D and therefore goes extinct.

In contrast to the mosquito suppression model, the third plot represents a gene drive that would modify mosquitoes to render them unable to transmit malaria. Drive gene D causes DW parents to produce gametes that are 100 percent D and 0 percent W, as in the suppression model. With the modification method, however, DD individuals are fertile. The population evolves to 100 percent D and does not go extinct.







Barbara Aulicino/Jenny Foerst

D and W are both maintained in the population. Instead, D goes all the way to 100 percent, at which point every mosquito is sterile, and the population goes extinct.

Inspired by the results of these small-cage experiments, the Crisanti group recently initiated a new set of tests. In a high-security facility built in Terni, Italy, the group is using large cages that computers control to mimic natural environmental conditions, such as light, temperature, and humidity. The next step, pending approval, will be an open field test. Gene-drive research is moving fast.

So far we have described what happens in a single population that contains driving gene D and wild-type W. The analysis becomes more complicated when we consider a country or an entire continent where many local populations of mosquitoes exist and the following conditions apply: The populations have W at 100 percent, biologists introduce D into a few of those populations, and migrants move from one population to another. In this multigroup setting, if extinction occurs in a local population, those denuded locales become repopulated by wild-type mosquitoes. The result is that D increases in frequency in groups that contain both D and W, but groups in which W is common avoid extinction and send out migrants more successfully than groups in which D is common. Using estimated rates of between-group migration, modeling by Burt and colleagues suggests that mosquitoes do not entirely disappear from locales in which D has been introduced, but their numbers are substantially reduced (by about 90 percent).

Because the extinction approach is biologically feasible, ethical questions must be considered. If the gene drive is inserted into mosquitoes in the wild, will the ecosystem crash or suffer a major disruption? For example, more than 400 mosquito species exist in India, but only 4 to 6 of those species are significant in the spread of malaria to humans. Although extinguishing a species can sometimes cause a major ecosystem disruption, extinguishing these 4 to 6 species is unlikely to do so.

Frank Kimaro, USAID Boresha Afya Lake Western Zone/U.S. Government Works

In Tanzania, a child receives a rapid diagnostic test on World Malaria Day 2018. Children five years old and younger are disproportionately affected by malaria. In 2018, 67 percent (272,000) of all malaria deaths worldwide were of children in this age group, according to the World Health Organization.

True, some bats eat blood-feeding mosquitoes, but they eat numerous other organisms as well, including mosquitoes that do not feed on humans. This property of the food chain suggests that the probability of the extinction strategy's crashing the ecosystem is very small, although unforeseen consequences are always possible.

Another problem with the mosquito suppression approach is less speculative: If the mosquitoes in one valley are driven to extinction, nothing prevents mosquitoes in a neighboring valley from flying in and repopulating. Extinction by gene editing is therefore subject to the same problem as old-fashioned insecticide: Repeated applications of gene drives will be required, just as is true for the insecticide DDT. How many months or years would lapse between the extinction of mosquitoes in one locale and a migration that repopulates it? The answer depends greatly on the specific context, so it is hard to provide a blanket estimate. Although even a brief respite from malaria may provide real human benefits, this problem attending the extinction approach explains the appeal of an alternative approach.

Option 2: Mosquito Modification

Instead of exterminating mosquitoes, a second option is to make them unable to spread malaria—which could benefit mosquitoes and humans alike. Mosquitoes stop eating for two weeks after they are infected with malaria. Once an infected mosquito starts to feed, the parasite manipulates the mosquito's behavior, leading it to eat many small blood meals rather than a few large ones. A drive gene that causes the mosquito to kill the malaria inside its body, or to expel the malaria without injecting it into human beings, may have a double evolutionary advantage: It would be favored in the competition between genes that occurs inside of DW heterozygotes, and DD organisms would be fitter than WW organisms (*see sidebar on page 167*).

The mosquito suppression strategy creates vacant locales, which mosquitoes from other locales can colonize, whereas the modification strategy creates no such unoccupied domains.

This gene drive avoids problems that the suppression strategy faces. The mosquito suppression strategy creates vacant locales, which mosquitoes from other locales can colonize, whereas the modification strategy creates no such unoccupied domains. The modified population continues to exist and carries the drive gene at 100 percent. The wild-type gene that it drove to zero in one population may be present elsewhere, but that outsider cannot enter the modified population and displace the drive gene. The WW migrant will be at a selective disadvantage when it enters a population of organisms that are DD.

When biologists talk about "eradicating malaria," nonscientists often assume that their goal is to rid the whole planet of the disease in one fell swoop. Realistically, the nations of the world probably lack both the resources and the will to carry out this coordinated global undertaking. If any such project is to succeed, it must proceed piecemeal, with malaria eliminated in one locale, then another, and so on. When malaria is finally eliminated everywhere, eradication will have been achieved. If the modification strategy is used, this stepwise program is plausible; if the suppression strategy is used alone, it is not.

An ethics question remains: If the malaria parasite is removed from a mosquito population and the population continues to exist, will that modified population create a vacancy that a new parasite will fill, perhaps making matters worse for human beings? The probable answer is *no*. Only about 1 to 5 percent of female mosquitoes, at any given time, carry malaria. This statistic indicates that an already ample opportunity has existed for other parasites to move in, but so far none have.

Another ethical concern pertains to both the suppression and modification strategies. Perhaps a driving gene will jump from one species to another that is not closely related, such as humans, propelled by a virus that facilitates horizontal gene transfer. This pathway for gene flow exists alongside the vertical transmission from parent to offspring. The worry here is that a gene inserted into mosquitoes would find its way into the human genome, with disastrous consequences for us. This scenario has virtually no chance of happening in the foreseeable future, however, because CRISPR drives rely on two highly specific constraints: the sequence of the targeting component of the "scissors," which tells it where to cut, and a nearly perfect alignment of DNA sequences between donor and recipient sites into which the genetic element is to be copied. Scientists can choose both these factors to be unique to the genetic element inserted at its intended site, with the result that the insertion occurs only in the species of choice. A jump to even a closely related species that lacks these DNA sequences would be virtually impossible.

A more plausible scenario would be that, if the drive gene were not designed carefully, an organism carrying that gene in the target species might mate with an individual in a closely related species and produce viable, fertile hybrids. In plants, the drive gene might indeed jump relatively far, because plants apparently hybridize more readily than animals. For insects, however, the gene drive would be limited to spreading within the same genus. In any case, designing CRISPR gene drives that confine themselves to the targeted species should be possible. Laboratory tests will show whether spread to related species is likely, in which case the effect would be simply that the additional species are more resistant to spreading malaria.

If the modification strategy eliminates malaria in a locale, the game may not be over. True, gene-drive D displaces wild-type W, and the population persists with all the individuals now having two copies of gene D. True, W individuals from elsewhere cannot invade this population. The sticking point is that new mutations may arise that disable D. Natural selection is a process in which fitter traits replace traits that are less fit. D's being fitter than W does not prevent a new trait from arising that outcompetes D. Evolution does not stop. This is a problem in eradicating any infectious disease, however, not only malaria. It is not a cause for despair, but it does mean that biological solutions may have limited shelf lives.

Because of the shelf-life problem, the modification strategy may face an invadability problem akin to the one that the suppression strategy faces. The problem with the suppression strategy is that a vacant locale may be repopulated by migrants with the old gene W. The problem with the modification strategy, by contrast, is that the modified population may be invaded by a gene that arises by mutation and exhibits some advantage over D. That said, successful invasion would likely occur more quickly with the suppression strategy than with the modification strategy.

Prospects and Risks Versus Benefits

The Crisanti group's experiments provide evidence that the suppression strategy is feasible. Does evidence exist that the modification strategy is feasible too? The answer is *yes*. Remember the transmission-blocking antibodies that were developed to provide an altruistic vaccine? As published in 2012, Anthony James's lab at UCI developed a set of altruistic genes that encode antibodies that are made in female mosquitoes only after they draw blood. (Only female mosquitoes bite humans, and these females need a blood meal to reproduce.) The lab's experiments showed that these antibodies are 100 percent effective in blocking the transmission of the most lethal form of malaria.

After the Bier lab devised the first CRISPR gene drive in insects, the two labs collaborated, combining the gene drive from the Bier lab with the antimalarial genes from the James group. The result was a mosquito that delivers transmission-blocking antibodies to almost 100 percent of its progeny. Experiments provided proof-in-principle for the feasibility of this gene drive, which spreads to the mosquitoes' antibodies, doing the mosquitoes no harm while also preventing them from spreading the malaria parasite from one human host to another. As in the experiments conducted by the Crisanti group, experiments with laboratory cages of mosquitoes were constructed in which all individuals were initially either WW homozygotes or DW heterozygotes. The results suggest that it would take only one to two seasons (10 to 20 mosquito generations) from the time of introducing the new gene into a wild population to its reaching 100 percent.

Unintended consequences are possible in any undertaking, but to allow that possibility to govern action is to choose inactivity, which extracts a price of its own. The price is enormous—some 2 million people will suffer from malaria each year, and some 500,000 will die. Those of us who live in countries that are free of malaria may feel no impetus to accept a risk if that risk is the price for saving lives elsewhere. But those of us who live in societies immersed in the malaria plague may be more inclined to accept some risk. Would malaria-free countries reject a gene drive that could eradicate Alzheimer's disease or cancer?

Ethan Bier is a distinguished professor and science director for the Tata Institute for Genetics and Society at the University of California, San Diego, and holds the Tata Chancellor's Endowed Professorship in Cell and Developmental Biology. Elliott Sober is William F. Vilas Research Professor and Hans Reichenbach Professor at University of Wisconsin–Madison. He has published widely on philosophical issues concerning evolutionary biology, philosophy of probability and statistics, scientific realism and instrumentalism, philosophy of cognitive science, and Occam's razor. Email for Bier: ebier@ucsd.edu

Bibliography

Burt, A. 2003. Site-specific selfish genes as tools for the control and genetic engineering of natural populations. *Proceedings of the Royal Society B: Biological Sciences* 270:921–928.

Curtis, C. F. 1968. Possible use of translocations to fix desirable genes in insect pest populations. *Nature* 218:368–369.

Gantz, V. M., and E. Bier. 2015. The mutagenic chain reaction: A method for converting heterozygous to homozygous mutations. *Science* 348:442–444.

Gantz, V. M., et al. 2015. Highly efficient Cas9-mediated gene drive for population modification of the malaria vector mosquito *Anopheles stephensi. Proceedings of the National Academy of Sciences of the U.S.A.* 112:E6736–6743.

Hammond, A., et al. 2016. A CRISPR-Cas9 gene drive system targeting female reproduction in the malaria mosquito vector *Anopheles gambiae. Nature Biotechnology* 34:78–83.

Lewontin, R. C., and L. C. Dunn. 1960. The evolutionary dynamics of a polymorphism in the house mouse. *Genetics* 45(6):705–722.

North, A. R., A. Burt, and H. C. J. Godfray. 2019. Modelling the potential of genetic control of malaria mosquitoes at national scale. *BMC Biology* 17:26.

Sober, E., and D. S. Wilson. 1998. *Unto Others: The Evolution and Psychology of Unselfish Behavior.* Cambridge, MA: Harvard University Press.

To view this article online, go to

www.amsci.org/magazine/issues/2020/may-june

Naming the Universe

The quick thinking of internationally minded astronomers led by John Herschel avoided stamping the Solar System with petty European rivalries.

Stephen Case

It was the autumn of 1846, and John Herschel (1792–1871), the British astronomer and natural philosopher, was not sleeping well. He had just put his foot into the century's most acrimonious astronomical dispute, and now he was being abused by those on both sides of the matter—his British colleagues on the one hand, and French astronomers and their European allies on the other. By the 1840s, Herschel, who was first knighted and later made a baronet by Queen Victoria, was one of the astronomical community's leading lights. As the son of William Herschel (1738–1822)—the musician-turned-astronomer who in 1781 discovered the first planet since antiquity and neatly doubled the known size of the Solar System—John had inherited his father's massive telescopes and method of sweeping the night sky for new objects beyond the Solar System. He had also inherited and extended his father's legacy to become the de facto spokesman of Victorian science. John Herschel's treatise on the scientific life, *A Preliminary Discourse on the Study of Natural Philosophy* (1830), was a contemporary best seller, and influenced a generation of thinkers who followed after him, from John Stuart Mill to Charles Darwin. Indeed, as the historian of science Walter F. (later Susan Faye) Cannon quipped in 1961, being scientific in the Victorian era meant simply to "be as much like [John] Herschel as possible."

But, for a few weeks in late 1846, even John Herschel didn't want to be John Herschel. French astronomers had just announced another new planet beyond the one that Herschel Senior had discovered back in 1781. Whereas William Herschel's planet (known today as Uranus) had been an accidental, serendipitous discovery, the location of this new one had been mathematically predicted by the French astronomer Urbain Le Verrier (1811–1877). Shortly thereafter, this prediction was confirmed by observation at the Berlin Observatory on the evening of September 23, 1846. The new planet was the first celestial body detected by mathematical analysis, a stunning achievement for mathematical physics and for Isaac Newton's gravitational synthesis.

To Herschel, the point wasn't who had observed the planet first, but that two astronomers had independently reached the same result in their predictions.

Herschel was thrilled by the discovery. However, he, along with a handful of other British astronomers, was also aware that someone else had been working on similar calculations, and that those calculations had come quite close to predicting the new planet's location, independent of Le Verrier's work. This person was the shy, retiring Cambridge mathematician John Couch Adams (1819–1892). Whereas Le Verrier was renowned in the astronomical community, Adams was almost completely unknown outside of England. Yet, based on Adams's calculations, the Cambridge Observatory had begun a slow, meticulous search for the new world prior to the announcement of the discovery in Berlin.

The result was that, when Le Verrier announced the successful discovery of the new planet, Herschel felt obliged to speak up publicly for Adams's work, making the British look like sore losers. Le Verrier and astronomers abroad were rightly indignant, and many in Britain were outraged too, wondering why Adams's work hadn't received more attention and possibly beaten the French to it. Herschel found himself in the middle of this brewing storm. The day after reading an angry public response from Le Verrier, Herschel told his friend William Whewell (1794–1866), Master of Trinity College, Cambridge, that he had been up all night drafting a response.

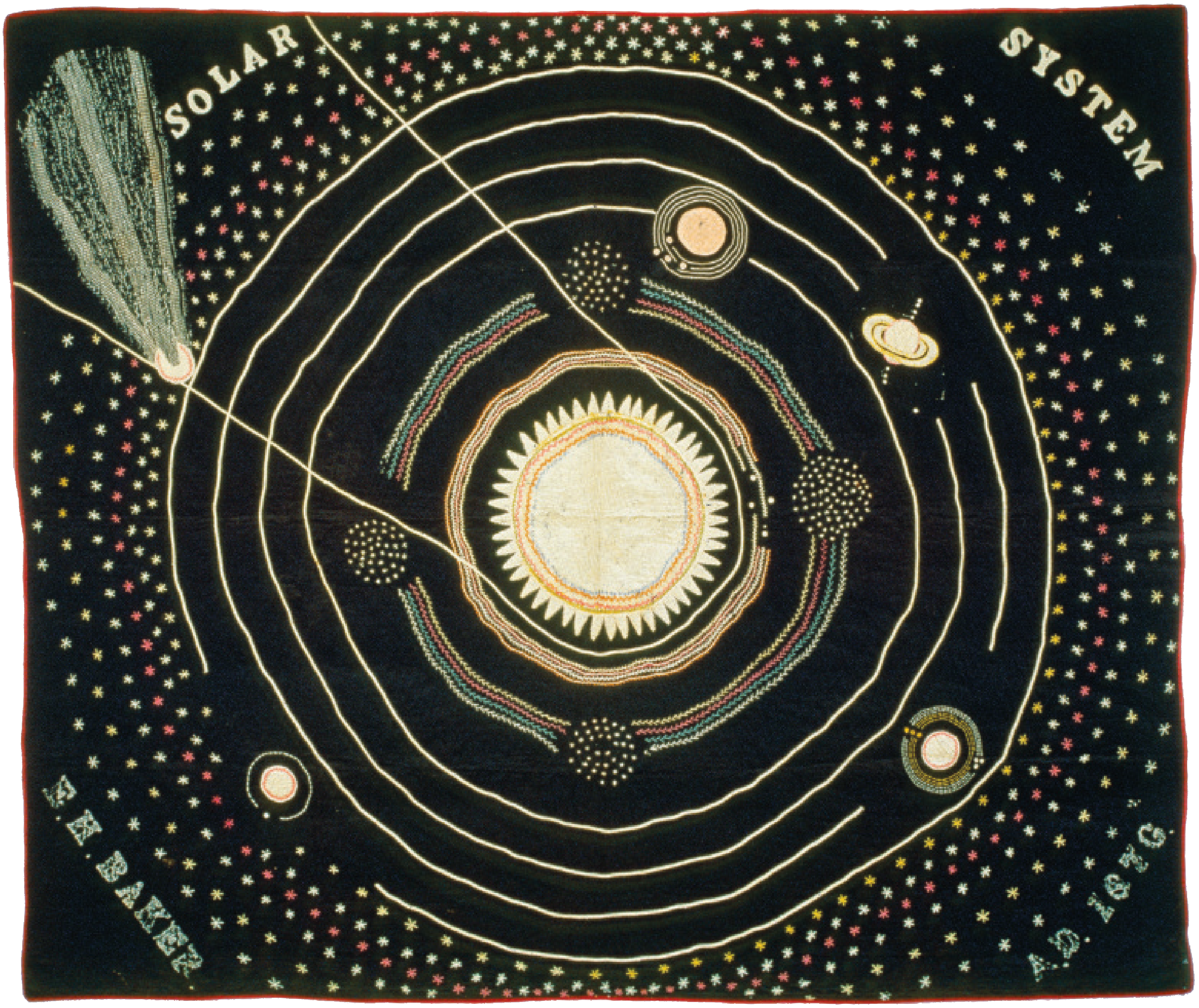
To his credit, Herschel thought he was being entirely fair. He had known about Adams's search, and had even alluded to it in his speech to the British Association for the Advancement of Science in September, less than a month before the planet was discov-

QUICK TAKE

Early-modern European astronomy was imbued with nationalism. Scholars raced to discover new objects, which they named in honor of their monarchs or themselves.

A near tie in the discovery of a new planet in 1846 brought the unregulated and inconsistent process of naming planets and moons to a head.

John Herschel developed and popularized a system of naming celestial objects that embraced classical models, avoiding attempts at nationalism and aggrandizement.



Division of Cultural and Community Life, National Museum of American History, Smithsonian Institution

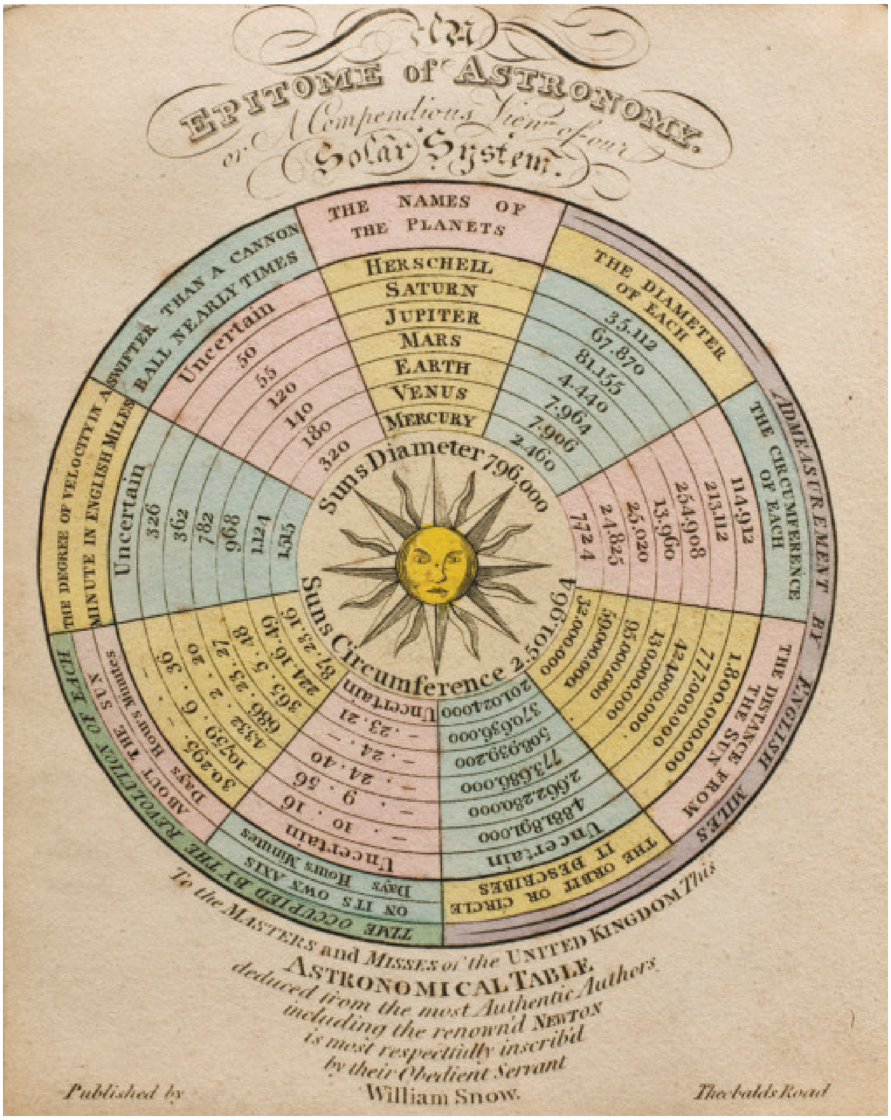
Ellen Harding Baker of Lone Tree, Iowa, completed this Solar System quilt in 1883. She likely was inspired by an 1874 trip to Chicago, where she viewed Sun spots and Coggia's Comet through a telescope. The mother of seven intended to use the quilt to teach astronomy, according to a brief mention in the *New York Times* on September 22, 1883. The quilt includes the eight known planets and their moons, including Neptune, which was discovered 30 years before Baker started the quilt in 1876 (*embroidered on the lower right corner*). The names of the planets could have been quite different if not for a precedent set mere decades before.

ered by Le Verrier. To Herschel, the point wasn't who had observed the planet first or what that meant for relative national prestige. Rather, the important fact was that two different astronomers had independently reached the same result in their predictions of both the planet's existence and its approximate location in the sky. This coincidence should not be a matter of contention or dispute, Herschel felt, but rather a reason for celebration because it showed the predictive power of mathematical physics.

Herschel, despite his public profile, had a self-effacing personality and hated controversy. Ever diplomatic, he immediately worked to smooth things over. His conciliatory approach seemed to work, and the controversy died down. Le Verrier and his colleagues were placated, and the Royal Society awarded the French astronomer the prestigious Copley Medal for his work leading to the planet's discovery. The next summer, Herschel even orchestrated a meeting at his home between Le Verrier and Adams, during which by all accounts the two "co-discoverers" got on fabulously.

Yet there still remained the delicate issue of naming the new planet, a consideration that threatened to reignite the entire controversy. Classically, the visible planets known since antiquity were named after Roman gods: Mercury, Venus, Mars, Jupiter, and Saturn. When John Herschel's father William discovered the planet now called Uranus, he broke this tradition, naming it the Georgium Sidus, or "George's Star," after King George III. George III had recently lost the British colonies in North America in the American Revolution but, through William's discovery and flattering name, the king could now be said to have gained an entire new world in the heavens.

There was some precedent for this kind of personal naming. When Galileo Galilei (1564–1642) in 1610 discovered that Jupiter had four moons, he gave them the collective name of the Medician Stars, after the Medici family, the rulers of Tuscany and eventual


An
EPITOME of ASTRONOMY,
or A Compendious View of our
Solar System.
THE NAMES OF THE PLANETS
HERSCHELL
SATURN
JUPITER
MARS
EARTH
VENUS
MERCURY
THE DIAMETER OF EACH
35.112
67.870
81.155
4.440
7.964
7.906
2.460
THE CIRCUMFERENCE OF EACH
114.912
213.112
254.908
13.960
25.020
24.825
7724
ADMEASUREMENT BY ENGLISH MILES
THE DISTANCE FROM THE SUN
1.800.000000
777.000.000
424.000.000
130.000.000
95.000.000
59.000.000
32.000.000
THE ORBIT OR CIRCLE IT DESCRIBES
Uncertain
4.881.891.000
2.662.280000
773.686.000
508.939.200
370.636.000
201.024000
TIME OCCUPIED BY THE REVOLUTION OF EACH
ON ITS OWN AXIS
Days Hours Minutes
Uncertain
10 . 16
9 . 56
24 . 40
. 24 . —
. 23 . 21
Uncertain
ABOUT THE SUN
Days Hours Minutes
30.293 . 6 . 36
10759 . 6 . 20
4332 . 2 . 27
686 . 23 . 18
365 . 5 . 48
224 . 16 . 49
87 . 23 . 16
THE DEGREE OF VELOCITY IN A MINUTE IN ENGLISH MILES
Uncertain
326
362
782
968
1.124
1.515
SWIFTER THAN A CANNON BALL NEARLY TIMES
Uncertain
50
55
120
140
180
320
Suns Diameter 796,000
Suns Circumference 2.501.964
To the Masters and Misses of the United Kingdom This
Astronomical Table
deduced from the most Authentic Authors
including the renown'd Newton
is most respectfully inscrib'd
by their Obedient Servant
William Snow.
Published by
Theobalds Road

© Science Museum/Science & Society Picture Library

This chart of the Solar System lists the seventh planet as Herschel in honor of William Herschel, who discovered the planet in 1781. Herschel himself named the planet Georgium Sidus after King George III. But by the mid-19th century, many people called the planet Uranus in keeping with the rest of the planets, which were named after mythical gods from antiquity.

patrons of Galileo. But by the time of the discovery of Le Verrier's world in 1846, the name Georgium Sidus was falling out of favor for Uranus; no one called the moons of Jupiter the Medician Stars; and all the minor planets discovered since 1801 (known today as asteroids) had been given names from Greek mythology. It seemed that the heavens were becoming neutral ground—the names were clearly Eurocentric but at least classical, with no immediate nationalist connotations.

The controversy over Le Verrier's planet threatened to undo all this. Le Verrier, it turned out, was eventually convinced by his French colleagues that the planet—which most agreed he had the right to name, British claims to the contrary notwithstanding—should be named after him and called simply Le Verrier. Indeed, Le Verrier attempted to recruit Herschel's support for this idea, writing to Herschel at the end of November 1846 that he (Le Verrier) would henceforth refer to Uranus only as Herschel, after its original discoverer. If William Herschel's planet was named after its discoverer, it only made sense that Le Verrier's planet could be named the same way. John Herschel once again found himself in an awkward position. As the only other astronomer with a personal stake in the celestial naming scheme, and as a central and leading member of the nascent international scientific community, his opinion held sway.

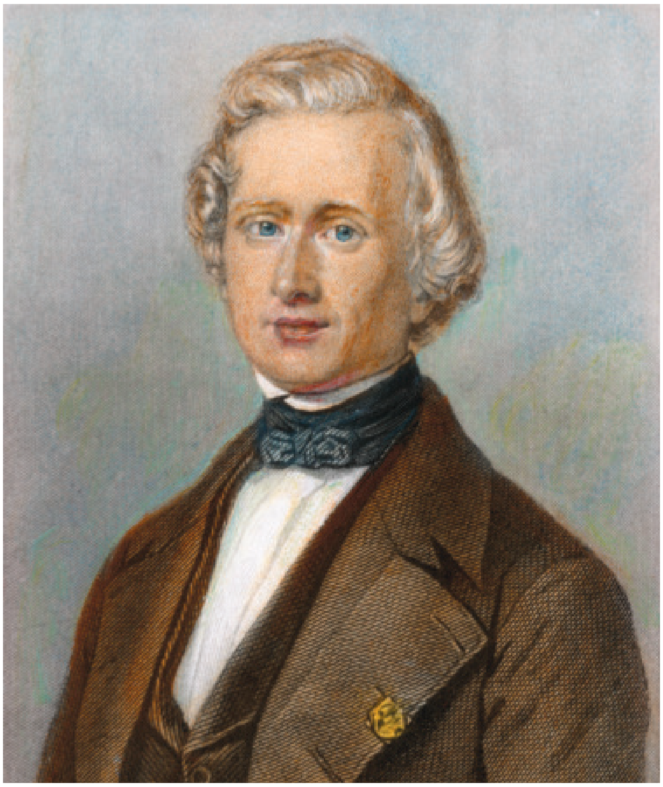
By now, Herschel didn't want anything more to do with the controversy. As he wrote to his friend Whewell, "I have said enough . . . to get heartily abused in France, and I don't want to get hated in England for saying more." Besides, he personally favored a mythological naming scheme for the planets, and had long abandoned the name Georgium Sidus for the planet his father had discovered, referring to it instead as Uranus.

Yet if Herschel started an argument with Le Verrier, it could rekindle the entire dispute about priority, especially as other British astronomers—affronted by the idea of a Planet Le Verrier—were arguing that Adams had as much right to name it as Le Verrier. And worse, the name that many British astronomers were arguing for was Oceanus, a loaded moniker if there ever was one. As one observer pointed out, the French, who had been defeated within recent memory by the might of the British navy, were as likely to accept Oceanus as they were if the British had suggested Wellington, after Napoleon's opponent at Waterloo.

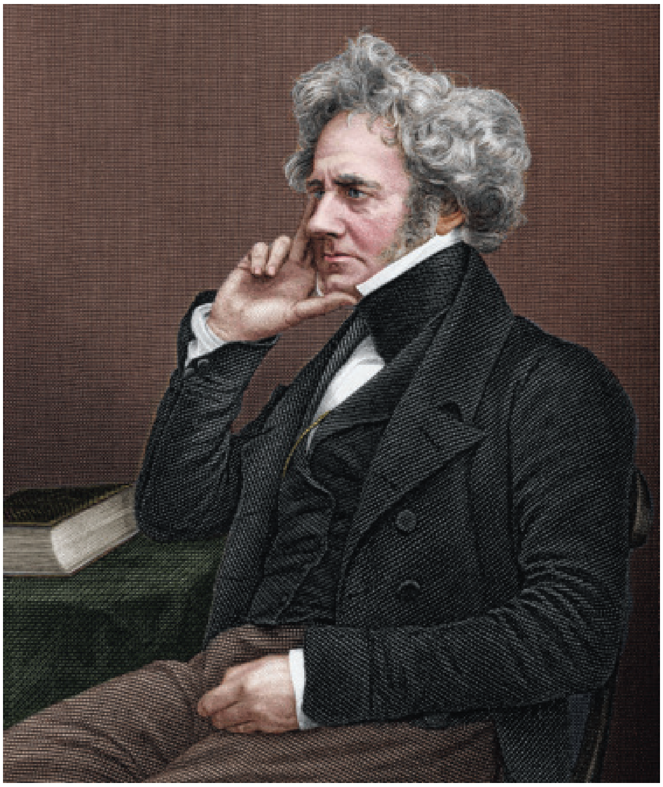
Then Herschel happened upon a plan to avoid this "confounded scrape" altogether. He realized that he could do a clever end-run around the dilemma by moving to establish a nomenclature not for planets, but for their moons instead. This ploy worked, and it remains the basis of naming satellites in the outer Solar System.

A Universal Naming System

To understand Herschel's plan, we need to take a brief look at how moons were named in the Solar System up to this point—or rather, how they weren't named. As already mentioned, when Galileo discovered the moons of Jupiter, he didn't give them individual names. He simply referred to all four as the Medician Stars. Simon Marius (1573–1624)—a German astronomer who spotted the moons at roughly the same time as Galileo—did give them names, though not the ones that might be expected. He thought they should be referred to by planetary analogues: the Mercury of Jupiter, the Venus of Jupiter, the Saturn of Jupiter, and the Jupiter of Jupiter. (He didn't assign a Mars of Jupiter for astrological reasons, and also because none of the moons had Mars's reddish tint.) If these names were too confusing, he offered names that he said his friend



Sarin Images/Granger



Sheila Terry/Science Source

When Urbain Le Verrier (*left, circa 1847*) discovered a new planet in 1846, there was no formal system for naming celestial objects. Colleagues convinced Le Verrier that he should name the planet after himself, but John Herschel (*right, circa 1860*) managed to expand and popularize a system of naming celestial objects that avoided attempts at nationalism or aggrandizement.

Johannes Kepler (1571–1630) had suggested: Io, Europa, Ganymede, and Calisto—all mythological companions (amorous or otherwise) of Jupiter.

These names didn't catch on. For example, when the French-Italian astronomer Giovanni Domenico Cassini (1625–1712) calculated the first tables of the orbits of these moons, he offered his own names: Pallas, Juno, Themis, and Ceres. In practice, though, Cassini—along with most other astronomers well into the modern period—simply referred to the moons of Jupiter by number: I, II, III, and IV. Planets were named, but there didn't seem to be any need for naming their satellites.

Part of this reasoning was that there simply weren't many satellites to name. After the four moons of Jupiter were discovered, it was almost half a century before the largest and brightest moon of Saturn was discovered. In 1655 when the Dutch astronomer Christiaan Huygens (1629–1695) announced his discovery of the moon known today as Titan, he felt no need to name it. Likewise, when Cassini discovered two additional moons of Saturn in 1672, he called them the first and second. Things got a bit more complicated in 1684 when Cassini discovered another two satellites, closer to the planet than the first three. This discovery entailed renumbering the moons, but even this potential confusion didn't prompt Cassini, or anyone else, to give the moons individual names. Instead, Cassini suggested that, like Galileo's moons, the moons of Saturn be known as the Sidera Lodoicea (stars of Louis) after King Louis XIV of France, "under whose Reign and in whose Observatory" the four new moons were discovered.

Historians of astronomy normally bring this story to a conclusion by explaining that, when John Herschel finally decided to give the moons of Saturn the mythological names they have today, it was to rectify this confusion. Here, he also had a familial claim. In 1789, his father William had discovered two more moons of Saturn, bringing the total of Saturnine satellites up to seven. Both of these new moons were interior to those already known. William Herschel kept the moons numbered but added his two new moons to the end of the numbering scheme, meaning that the moons of Saturn (moving outward from the planet) became known as 6, 7, 1, 2, 3, 4, and 5. When John Herschel spent several years at the Cape of Good Hope in the 1830s studying the southern skies, Saturn and its confused system of moons was ideally positioned for viewing. It was then, as is usually explained, that he straightened out this confused system of numbering by giving the moons of Saturn individual, classical names—Mimas, Enceladus, Tethys, Dione, Rhea, Titan, and Iapetus (reckoning outward from the planet)—the titans of Greek mythology.

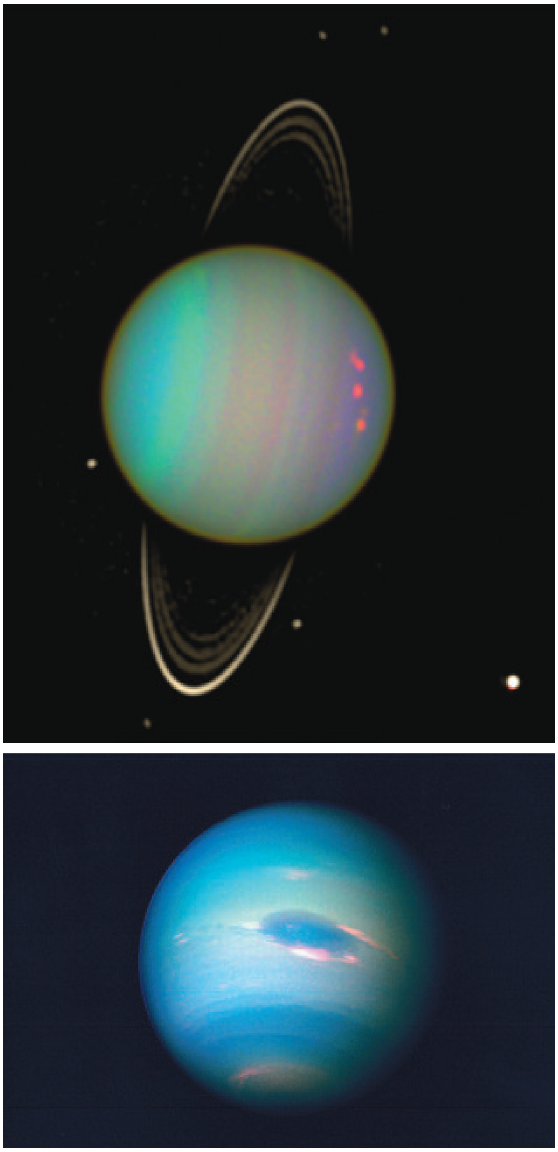
The moons of Saturn became an antithesis to earlier attempts to recognize specific individuals or patrons in the heavens.

As Herschel explained, because the previous naming scheme was:

> practically annoying, and a source of frequent error and mistake, I have used for my own convenience . . . a mythological nomenclature, which, however, I do not presume to recommend to the adoption of others, though I am persuaded that *some* nomenclature other than the equivocal one in actual use, will be found necessary by all who observe these bodies.

As for his suggested names, "As Saturn devoured his children," Herschel pointed out, "his family could not be assembled round him, so that the choice lay among his brothers and sisters, the Titans and Titanesses."

The only problem with Herschel's published explanation—that he had named the moons simply for clarity—is that it was offered in 1847, a decade after his observations of Saturn were actually made. Indeed, the very day that the mythological names for Saturn's moons appear for the first time in Herschel's diary is the same day that Herschel received the letter from Le Verrier pledging to refer to the Georgium Sidus as Herschel.



NASA/Erich Karkoschka (Univ. Arizona)

JPL/Ames Research Center

Scholars had known about the six planets closest to the Sun since antiquity, but in a 65-year span two more planets were added to the System: Uranus in 1781 (*top*) and Neptune in 1846 (*bottom*). The previously known planets were all named for Roman gods and goddesses, but there was no common standard for naming newly discovered celestial objects.

Naming Saturn's moons, it seems, offered Herschel an ideal way out of the Neptune controversy. While the debate on what the new planet would be called raged on, Herschel was in the midst of finalizing the *Results of Astronomical Observations made at the Cape of Good Hope*, the massive volume that was the outcome of his observing campaign at the Cape from 1834 to 1838. The *Results* represented the completion of history's first telescopic survey of the entire sky. It included a chapter on Saturn as well, and the discussion here on the planet and its moons offered the perfect opportunity for Herschel to introduce his new nomenclature, ostensibly for clarity. In fact, what Herschel's names for the moons did was help cement a nomenclatural system built on classical mythology, and ensure that names such as Herschel or Le Verrier had no place in the skies. Sponsored by the Duke of Northumberland, the *Results* delivered Herschel's new nomenclatural system as part of an elaborate and impressive astronomy tome, presented to Queen Victoria and Prince Albert in 1847, and shipped out to observatories and astronomers all over the world.

Herschel's plan worked. The naming scheme for Saturn's moons was immediately adopted by other astronomers. When the astronomer William Lassell (1799–1880) discovered another satellite of Saturn in 1848, he named it Hyperion, following the titanic naming convention. And, since then, all moons discovered around Saturn have followed this basic scheme. (In 2004 the International Astronomical Union, or IAU, broadened the naming convention to allow for giants from other mythologies because of the number of newly discovered satellites).

Lingering Biases

Not everyone was happy with Herschel's suggestion. The crotchety Scottish physicist David Brewster (1781–1868) felt it unnecessary to introduce more pagan deities into the heavens. Numbering the moons had been fine for centuries; what was the need to change it now? "If the houses of a street are numbered before it is completed," Brewster maintained, "the numbers must be changed whenever a new house is placed on a vacant area." Doing so for moons was better than "the admission of a brood of demigods" into the Solar System and, besides, what would become of the other planets? "We cannot allow the planet Saturn to have a monopoly of the gods." The moons of Jupiter would need similar names, as would any moons of Uranus and Neptune.

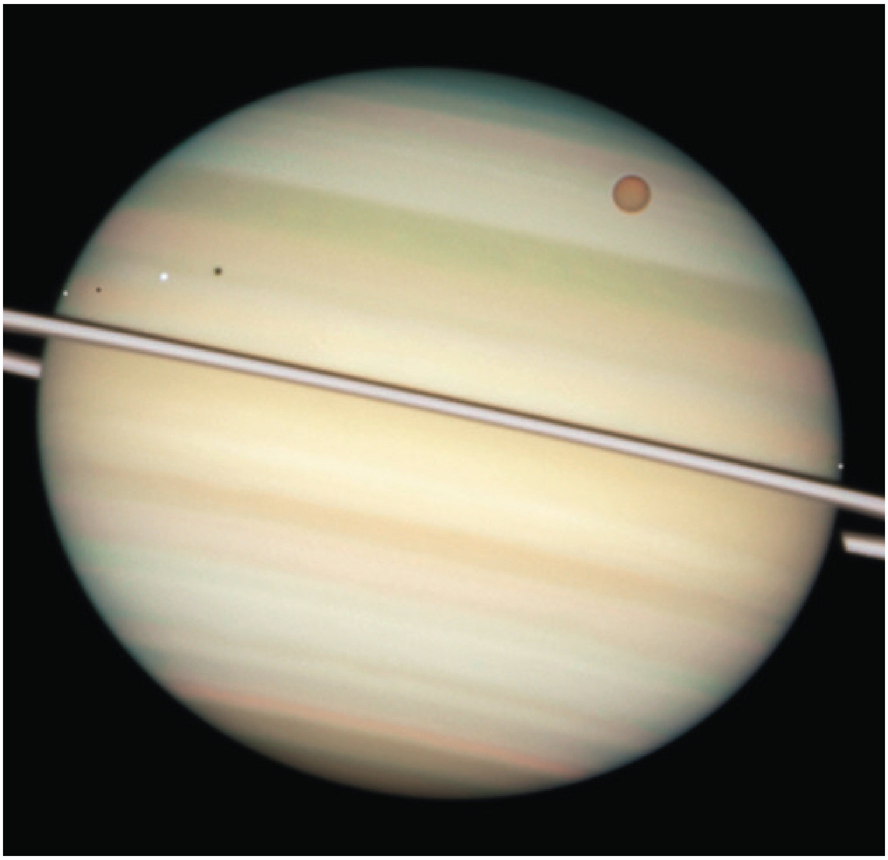
As far as the controversy over Le Verrier's planet, Neptune was already winning out over the name Le Verrier by the time Herschel's *Results* was published, and the new names for Saturn's moons helped to tip the scales of popular opinion firmly against contemporary, nationalistic names in the sky. Herschel's names were a turning point in Solar System nomenclature. The moons of Saturn became an antithesis to earlier attempts to recognize specific individuals or patrons in the heavens. Herschel used Saturn's moons as a means of depersonalizing the heavens at a time when international tempers were flaring. The gesture carried extra weight in the astronomical community because it came from Herschel—the only person outside the Neptune debate who had a personal stake in naming the planets. It was certainly lost on no one that by helping to establish a mythological nomenclatural system, Herschel was giving up any chance that Uranus would continue to be referred to by the name his father had given it.

This story has a curious epilogue because it turns out that Brewster's prediction was right: there were more satellites in the outer Solar System that eventually needed names, and John Herschel had one additional legacy to leave. When his friend Lassell discovered two moons of Uranus and rediscovered the two that William Herschel had spotted around that planet decades earlier, he wrote asking John Herschel to suggest names for them. And once again, Herschel was able to shape nomenclature, this time in a surprising way. He wrote to Lassell that he thought the names of sprites or fairies would be appropriate and offered Oberon, Titania, Umbriel, and Ariel—all but Umbriel were names from the work of William Shakespeare. (Umbriel came from Alexander Pope's 1717 poem *The Rape of the Lock*, though Herschel admitted that Pope was "hardly classical enough.") For Herschel, the literary source was less important than the theme of airy spirits.

Lassell was also initially worried that the suggested names would not be classical enough, but finally admitted it was probably safe for a planet discovered by an English astronomer to be attended by satellites named for characters from the work of English writers no longer living. The irony is that, whereas Herschel's names for Saturn's moons helped to depersonalize the heavens, his suggested scheme for Uranus's moons (now formally ratified by the IAU) enshrined what Shakespeare scholar Todd Borlik of the University of Huddersfield in England has referred to as "a stunning act of Anglo-American cultural imperialism" in the heavens.

Once again, contemporary popular culture was on Herschel's side. As Borlik has pointed out, the triumph of Romanticism throughout Europe by the mid-1800s meant that Shakespeare (though not so much Pope) was seen as a universal genius, rather than a particularly English one. Because of the Bard's immense cultural appeal during this period, Herschel's suggested names transcended cultural or nationalistic boundaries and allowed him the opportunity, whether he intended it or not, to enshrine English literature around the planet originally named for an English king.

Nomenclature in the Solar System and beyond remains a complex topic today. Officially coordinated and governed by the IAU, the process of naming objects in space extends from newly discovered exoplanets to the surface features of planets and moons in our own Solar System. As Herschel's role in the establishment of this nomenclature shows, despite the best efforts of astronomers to keep space names neutral, they're always entangled in human affairs—our history, our culture, and sometimes even our politics. And this is how it should be. Herschel's best attempts to keep names in space transnational still enshrined Eurocentric biases, and his second legacy around the moons of Uranus was even more tightly Anglocentric. Today, instead of a neutrality that is in principle unobtainable, a better goal is inclusion. The things we name in the universe—which in itself bespeaks a certain hubris—should be named for all of us, and recent strides to draw upon the mythology of cultures around the world, though they still have far to go, are at least steps in the right direction.



NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

The Hubble Space Telescope captured this image of four moons transiting Saturn in 2009. The large, orange circle is Saturn's largest moon, Titan. The three other moons are Enceladus, Dione (*both on the left, along with their shadows*), and Mimas (*at the far right*). Titan, Dione, and three other moons were discovered in the 17th century; William Herschel found Enceladus and Mimas in 1789. Astronomers referred to the moons by an inconsistent system of numbers, until John Herschel popularized a system of naming them after the mythical Titans.

Stephen Case is an associate professor of chemistry and the geosciences at Olivet Nazarene University in Illinois, where he works and teaches as a historian of science and as director of the Strickler Planetarium. His book Making Stars Physical: The Astronomy of Sir John Herschel *was published by University of Pittsburgh Press in 2018. This article was adapted from an essay previously published in* Aeon, *aeon.co. Twitter: @stephenrcase*

Bibliography

Borlik, T. A. 2014. Stellifying Shakespeare: Celestial imperialism and the advent of universal genius. *Shakespeare in Southern Africa* 26:1–12.

Canon, W. F. 1961. John Herschel and the idea of science. *Journal of the History of Ideas* 22:215–239.

Case, S. 2019. A 'confounded scrape': John Herschel, Neptune, and naming the satellites of the outer Solar System. *Journal for the History of Astronomy* 50:306–325.

Ruskin, S. 2004. *John Herschel's Cape Voyage: Private Science, Public Imagination and the Ambitions of Empire.* Aldershot, England: Ashgate.

Smith, R. W. 1989. The Cambridge network in action: The Discovery of Neptune. *Isis* 80:395–422.

To view this article online, go to

www.amsci.org/magazine/issues/2020/may-june

The Rise of Parkinson's Disease

Many cases of this increasingly common neurodegenerative disease are preventable, and we may now know how.

Ray Dorsey, Todd Sherer, Michael S. Okun, and Bastiaan R. Bloem

Neurological disorders are the world's leading cause of disability. And the fastest growing of these conditions is not Alzheimer's but Parkinson's disease. From 1990 to 2015, the number of people living with Parkinson's more than doubled from 2.6 million to 6.3 million, according to a 2015 study in *Lancet Neurology*. By 2040, the number is projected to double again to at least 12.9 million, a stunning rise (*see the top figure on page 178*).

Neither our increased awareness of the disease nor our lengthening life spans can fully account for the upsurge in diagnoses that we now face. Our knowledge of another neurological disorder, multiple sclerosis, has increased too, and we have improved diagnostic tools for it. Rates for multiple sclerosis have indeed gone up, but that increase is nothing like the exponential rise of Parkinson's (*see the bottom figure on page 178*). As for aging, more people are, of course, living longer. For example, from 1900 to 2014, the number of individuals over age 65 in the United Kingdom increased about sixfold. However, over that same period, the number of deaths due to Parkinson's disease increased almost three times faster.

Parkinson's disease is characterized by tremors, slowness in movement, stiffness, and difficulties with balance and walking. It can also cause a wide range of symptoms that are not visible—loss of smell, constipation, sleep disorders, and depression. Most people with Parkinson's are diagnosed in their fifties or later. But it is not just a disease of the elderly. Up to 10 percent of those with the condition develop the disease in their forties or younger.

Parkinson's stems from a loss of nerve cells in a particular region of the brain that produces dopamine, the brain chemical that helps control movements such as walking. The disease has multiple causes including environmental hazards—air pollution, some industrial solvents, and particular pesticides. In addition, certain genetic mutations, head trauma, and the lack of regular exercise all increase risk.

While industrialization has increased incomes and life expectancies around the world, its products and by-products are also likely increasing the rates of Parkinson's. Air pollution began to worsen in England in the 1700s, metal production and its harmful fumes increased in the 1800s, the use of industrial chemicals rose in the 1920s, and synthetic pesticides—many of which are nerve toxins—were introduced in the 1940s. All are linked to Parkinson's—people with the most exposure have higher rates of the disease than the general population.

The evidence for this connection is overwhelming. Countries that have experienced the least industrialization have the lowest rates of the disease, whereas those that are undergoing the most rapid transformation, such as China, have the highest rates of increase. Specific metals, pesticides, and other chemicals have all been tied to Parkinson's in numerous human studies. When animals are exposed to many of these substances in lab experiments, they develop the typical characteristics of the disease.

Agricultural areas have the highest rates of Parkinson's. In Nebraska, the rates of the disease are two to four times higher in the state's rural, agricultural parts than in urban Omaha, according to a 2004 study in *Movement Disorders*. In Canada, investigators have found an almost perfect correlation between areas with the highest pesticide use and the highest rates of disease, as documented in a 1987 study in the *Canadian Journal of Neurological Sciences*. In France, rural areas have the highest rates of Parkinson's, as do the regions with the most vineyards, which often require intense pesticide use, according to a 2017 study in the *European Journal of Epidemiology*.

Farmers who are exposed to certain pesticides have a higher risk of developing the disease. In one 1998 study published in *Neurology*, the risk of developing the disease for farmers was 170 percent greater than that for nonfarmers. And the longer farmers have worked with pesticides, the greater their risk.

Pesticide risks are not limited to farmers. People who simply live in rural areas have high rates of Parkinson's disease. These individuals may be exposed to pesticides in the air that can drift into residential communities. In addition, pesticides can contaminate groundwater or well water. Private wells are often shallow and may be especially at risk for contamination from nearby pesticides. Moreover, in the United States, private well water is not subject to the same regulations as water that comes from public systems.

QUICK TAKE

The number of people with Parkinson's disease more than doubled from 1990 to 2015 and could double again by 2040. An aging population alone does not account for this rise.

Air pollution, metal production, certain industrial chemicals, and some synthetic pesticides are linked to Parkinson's. Yet we are doing little to manage known risk factors.

The authors contend that the United States should ban trichloroethylene, paraquat, and other chemicals linked to Parkinson's, which many other countries have already done.

Christophe Vander Eecken/Reporters/Science Source

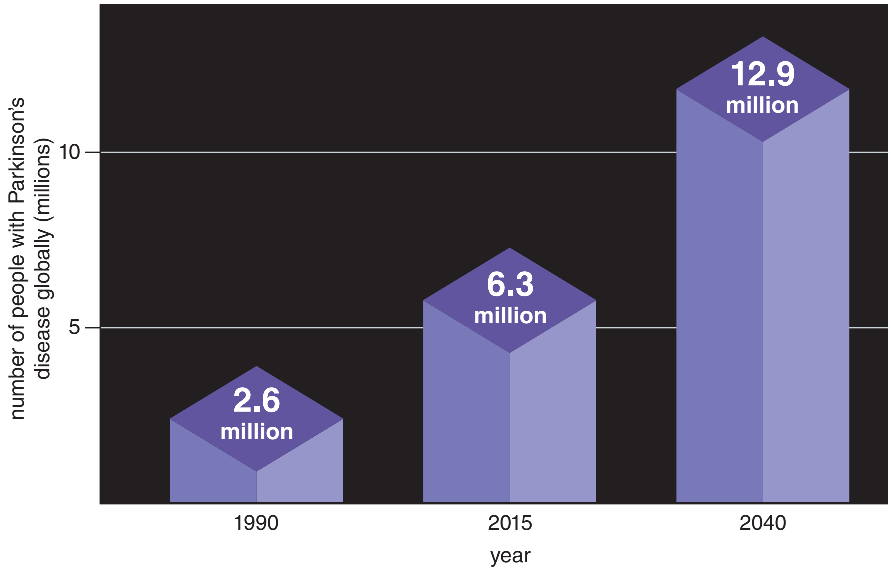
Agricultural areas have the highest rates of Parkinson's disease, and farmers who are exposed to certain pesticides have a higher risk of developing the disease. The longer farmers have worked with pesticides, the greater their risk. But these risks are not limited to farmers. People who live in rural areas have high rates of the disease as well, perhaps through exposure to pesticides when they drift into residential communities or when they contaminate groundwater or well water.

And then there are the rest of us. We eat fruits, vegetables, nuts, and grains every day that have been doused in pesticides. What kind of risk are we all exposed to? We do not know. Assessing pesticide exposure from foods and documenting individuals' dietary habits over a lifetime—given that Parkinson's takes decades to unfold—are challenging. But this research is needed. Until then, we are left with educated guesses. We do know that organic foods have much lower levels of pesticide residues than conventional choices.

Despite the vast evidence, we are doing little to manage these threats (*see "How Property Rights Can Fight Pollution," March–April 2020*). The U.S. Environmental Protection Agency (EPA) had at one time proposed banning one of the chemicals that is tied to Parkinson's, a solvent called *trichloroethylene*. But after lobbying by the chemical industry, the EPA decided in 2017 to postpone the ban indefinitely. The uses of trichloroethylene have been so numerous and widespread—in washing away grease, cleaning silicon wafers, removing spots in dry cleaning, and even, until the 1970s, decaffeinating coffee—that almost all of us have been exposed to it at some point in our lives. Some of these uses continue today. Almost half of Superfund sites—land so polluted that the EPA or the responsible parties have to clean it up—are contaminated with trichloroethylene. Thousands of other sites are polluted across the country.

As a result, as reported by the EPA, up to 30 percent of the U.S. drinking water supply has been contaminated with trichloroethylene. Because it readily evaporates from groundwater and soil, the solvent, like radon, can enter homes or offices through the air, undetected. Parkinson's is not even the most concerning safety risk. According to the EPA, trichloroethylene also causes cancer.

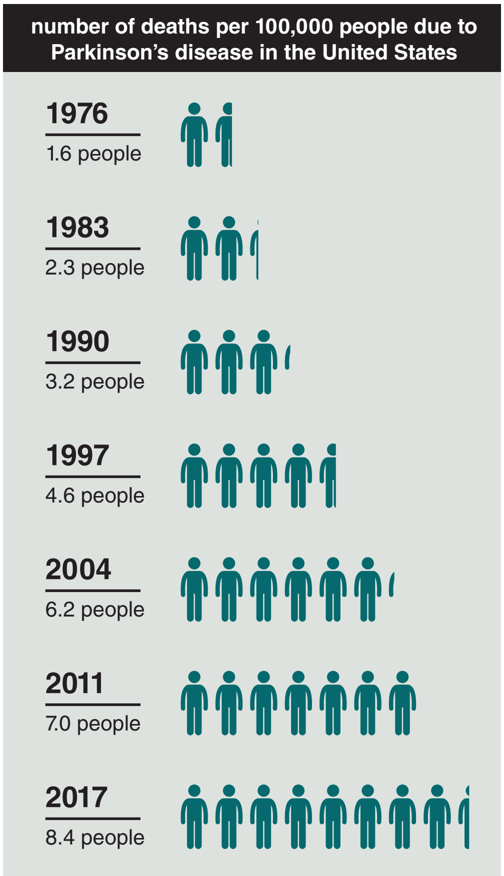
But trichloroethylene is only one dangerous chemical that we have failed to protect ourselves against. *Paraquat* is a pesticide so toxic that 32 countries, including China, have banned it. Exposure to the chemical increases the risk of Parkinson's by 150 percent, according to a 2011 study in *Environmental Health Perspectives*. Yet the EPA has done little. And as the agency charged with protecting our environment sits, paraquat's use on U.S. agricultural fields has doubled over the past decade, according to data from the U.S. Geological Survey's Pesticide National Synthesis Project.



The number of people with Parkinson's disease more than doubled between 1990 and 2015 and is projected to double again by 2040. (Figure adapted from E. R. Dorsey and B. R. Bloem, 2018.)

The nerve toxin *chlorpyrifos* is the most widely used insecticide in the country, drenching golf courses and dozens of crops, including almonds, cotton, grapes, oranges, and apples. It has been linked not only to Parkinson's but also to problems with brain development in children. Again, the EPA has shelved a ban. When a federal court stepped in to take action against the chemical, the Trump administration appealed. And in July 2019, in response to a court ordering a final ruling, the EPA decided that it would allow continued use of chlorpyrifos.

The number of cases of Parkinson's disease is rising at an alarming rate, but we know how to slow this increase—if we are just able to pay attention to what the epidemiological evidence is telling us. All the evidence indicates that the full effect of the Parkinson's pandemic is not inevitable but, to a large extent, preventable. The four of us—one neuroscientist and three neurologists who specialize in Parkinson's—have devoted most of our professional lives to this disease. While we are hopeful about making our patients' lives better, our true passion is preventing people from ever having to face Parkinson's. We are frustrated when we see women and men in our clinics who have suffered head trauma or been exposed to pesticides on a farm, solvents at work, contaminated groundwater in their neighborhoods, or polluted air in their homes. All these risks for Parkinson's can be mitigated. We humans have helped create this pestilence. And we can now work to end it.



The number of people who succumb to Parkinson's each year has been increasing steadily. (Data from: U.S. National Center for Health Statistics, National Vital Statistics System, Mortality Data.)

The Ghosts of Pesticides Past

Over the past half century, we have begun to identify the worst risks and address them. The insecticide DDT (short for *dichlorodiphenyltrichloroethane*) was once considered a miracle compound. In the 1930s, the Swiss chemist Paul Hermann Müller was looking for a chemical that could kill insects that were destroying crops and spreading disease—without harming the plants. Müller, a nature lover, tested hundreds of chemicals before coating the inside of a glass box with DDT, a colorless, tasteless, and almost odorless nerve toxin. He placed houseflies into the container, and they bit the dust. Müller had found his answer.

In 1948, Müller received the Nobel Prize in Medicine. But DDT was not the miracle chemical that Müller had envisioned. Beginning as early as the 1940s, its harmful effects on the health of wildlife, humans, and the environment were identified and detailed, including in Rachel Carson's 1962 book *Silent Spring*. Even though it was banned half a century ago, DDT persists in the environment—and in our food supply. It becomes more concentrated as it makes its way up the chain to human consumption. The pesticide is then stored in our fatty tissues.

Because of the widespread use of DDT and related chemicals, some are detectable in nearly everyone. In 2003 and 2004, more than 30 years after the insecticide was banned, the U.S. Centers for Disease Control and Prevention (CDC) tested the blood of about 2,000 people ages 12 and older. The researchers were looking for DDT and its metabolite, or breakdown product, *dichlorodiphenyldichloroethylene* (DDE). They found in their 2009 report that "a small proportion of the population had measurable DDT [and] most of the [U.S.] population had detectable DDE" in their blood. For Parkinson's, what matters more are the concentrations of chemicals in the brain, which may be several times those in blood, according to the Extension Toxicology Network, because DDT dissolves in fat.

Around the same time that the risks of DDT were being recognized, a newer pesticide was also coming onto the scene. Vietnam veterans and up to 4 million Vietnamese came into contact with Agent Orange during the Vietnam War. Named for the color of the 208-liter barrels in which it was stored, Agent Orange was an herbicide mixture designed to kill vegetation and crops in the tropical forests so that aircraft fighters could spot the enemy below.

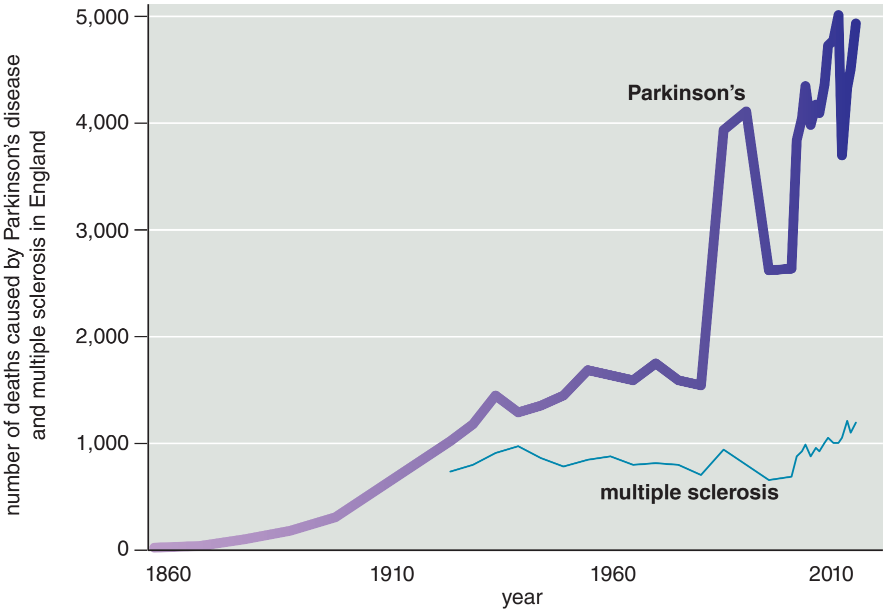
From 1965 to 1970, an estimated 45 million liters of Agent Orange were sprayed in Vietnam, according to a 2003 *Nature* paper. There has been no large-scale study of the effect of this exposure on the health of the Vietnamese or war veterans. Smaller studies, however, have linked Agent Orange to many problems in these populations, including birth defects, cancer, and Parkinson's, as summarized in a 2007 paper in *Science* by Richard Stone of the Veterans Health Administration. The evidence is sufficient that veterans who were exposed to Agent Orange and now have Parkinson's are eligible for disability compensation and health care from the U.S. Department of Veterans Affairs.

Another pesticide adds to the story and is also linked to Parkinson's. In the 1960s, the U.S. Food and Drug Administration had set a zero tolerance level for a pesticide called *heptachlor* in foods. In 1978, the Pineapple Growers Association of Hawaii and the state of Hawai'i were granted an exemption that allowed heptachlor to be sprayed on pineapples but prohibited their use as livestock feed within one year of spraying the fruit with the chemical. Then, in 1982, it was discovered that some contaminated green pineapple tops apparently had slipped into the feed before the year was up. Testing found that 7 of the 19 dairies on O'ahu had heptachlor levels in their milk that were three to six times the acceptable state level. Two months after the contamination was detected, Hawai'i's state health director ordered all fresh milk removed from stores and schools.

During those two months, Hawaiians were exposed to high levels of the pesticide. Leland Parks, a scientist at the Pacific Biomedical Research Center in Honolulu, tested samples of breast milk from nursing mothers and found that the average level of heptachlor contamination had increased fourfold.

By coincidence, Japanese researchers had launched a Honolulu Heart Program in the 1960s to follow more than 8,000 men of Japanese ancestry living on O'ahu for the development of heart disease. As part of that study, individuals completed diet surveys including questions on milk consumption. A subset had agreed to have autopsies performed at the time of their death. The research team examined the brains of 449 of them.

The investigators' findings, published in 2016 in *Neurology*, were remarkable. They found that the density of nerve cells in the *substantia nigra*, the area of the brain affected by Parkinson's, was lowest in those who consumed the most milk. Researchers also found another potential clue: The brains of those with Parkinson's were more likely to have the remains of heptachlor. These findings were supported by other studies. According to the CDC, some have found that levels of a related pesticide called *dieldrin*—which was widely sprayed on corn and cotton in the United States until 1970 (all uses were banned in 1987)—are also more likely to be found in the brains of people with Parkinson's.



The increase in the number of Parkinson's disease cases in England cannot be explained by an aging population or better diagnosis alone. Multiple sclerosis, another neurological disease, also has comparably improved diagnostics, but has not seen the exponential rise observed in Parkinson's deaths. Changes in coding in the 1980s likely contributed to the fluctuations in deaths recorded during this period. As for age, the rate of increase in Parkinson's far outpaces the increase in the elderly population in the United Kingdom. (Figure adapted from R. Dorsey et al., 2020.)

We eat fruits, vegetables, nuts, and grains every day that have been doused in pesticides. What kind of risk are we all exposed to? We do not know.

The blood levels of these pesticides that dissolve in fat, such as DDT, heptachlor, and dieldrin, are also higher in individuals with Parkinson's.

Although DDT, heptachlor, and dieldrin were banned from use on crops in the United States and other industrialized countries in the late 20th century, use of the pesticides shifted to less industrialized nations, including India and China. Even though China, for example, has now banned these pesticides, it used to be a major producer and consumer of them. As a result, the Chinese have high

Everett Collection Inc./Alamy Stock Photo

From 1965 to 1970, during the Vietnam War, an estimated 45 million liters of the herbicide Agent Orange were sprayed in Vietnam to kill vegetation so that aircraft fighters could see the enemy below. There has been no large-scale study of the effect of this exposure on the health of the Vietnamese or war veterans. Smaller studies, however, have linked Agent Orange to many problems in these populations, including Parkinson's.

D.D.T.
Powerful Insecticide
Harmless to Humans
TODD

Pictorial Press Ltd/Alamy Stock Photo

In the 1940s DDT was considered harmless to humans and regularly sprayed on neighborhoods; here children play in the sprays at the beach in New York. Even though DDT was banned half a century ago, it persists in the environment—and in our food supply. It becomes more concentrated as it makes its way up the chain to human consumption. The pesticide is then stored in fatty tissues, including the brain. DDT has been linked to Parkinson's disease. Because of the widespread use of the pesticide, DDT and its breakdown products are detectable in nearly everyone in the United States. It has also been found in the breast milk of women living in Spain, Nicaragua, Taiwan, and the Spanish Canary Islands as recently as 2014.

concentrations of the residues in milk from nursing mothers and increasing rates of Parkinson's, according to a 2005 study in *Chemosphere*.

The effects may be felt for years to come, especially in middle- and low-income nations. Remnants of the chemicals are still found in the milk supply of many countries, including Brazil, China, Ethiopia, and Uganda.

The accumulation of these pesticides in the body is not limited to adults who were exposed. They can be passed on to subsequent generations. As the Hawai'i case showed, nursing women who ingest these chemicals from dairy or meat products can deliver them to their babies through their breast milk. DDT and similar pesticides were found in the breast milk of women living in Spain, Nicaragua, Taiwan, and the Spanish Canary Islands as recently as 2014.

This class of pesticides may also cross the placenta into the developing fetus. For example, dieldrin accumulates in body fats and is detectable in the brains of fetuses, according to 2001 research in *Environmental Health Perspectives*. The long-term effects of DDT, heptachlor, and dieldrin on fetuses and breastfed children—and whether these chemicals can increase risk of developing Parkinson's—are unknown but concerning.

The Danger of Paraquat Today

The United States banned DDT, Agent Orange, and heptachlor in the 1970s and 1980s. However, the United States has not banned all pesticides linked to Parkinson's. The one with perhaps the strongest link to the disease is still in widespread use: paraquat.

Paraquat has been used as a pesticide since the 1950s and is marketed as an alternative to the world's most popular weed killer, glyphosate, more commonly known as Roundup. Paraquat takes care of weeds that not even Roundup can kill. Today, it is used on farm fields across the United States, and its use continues to increase. The pesticide's primary uses are for corn, soybeans, wheat, cotton, and grapes.

Paraquat may be an excellent weed killer, but its effectiveness comes at an enormous price. A 2009 study in the *American Journal of Epidemiology* found that exposure to paraquat and another pesticide called *maneb* within 500 meters of one's home increased the risk of Parkinson's disease by a whopping 75 percent. Two years later, another study in *Environmental Health Perspectives* found that people who used paraquat—most notably farmers—were 2.5 times more likely to have Parkinson's than those who did not. A scientist at the National Institutes of Health who has investigated paraquat, Freya Kamel, told Danny Hakim of the *New York Times* in 2016 that the data were "about as persuasive as these things can get."

In the laboratory, paraquat reproduces the features of Parkinson's disease. In a 1999 study in *Brain Research*, A. I. Brooks of the University of Rochester and colleagues gave paraquat to mice, and their activity decreased. Paraquat also killed dopamine-producing nerve cells in the rodents' substantia nigras. The greater the amount of paraquat administered, the greater the number of nerve cells lost.

Even beyond Parkinson's, paraquat has substantial safety concerns. If it touches your eyes, it can damage the cornea and lead to blindness. If you breathe it in, it can cause internal bleeding. If you swallow a teaspoonful, it is fatal.

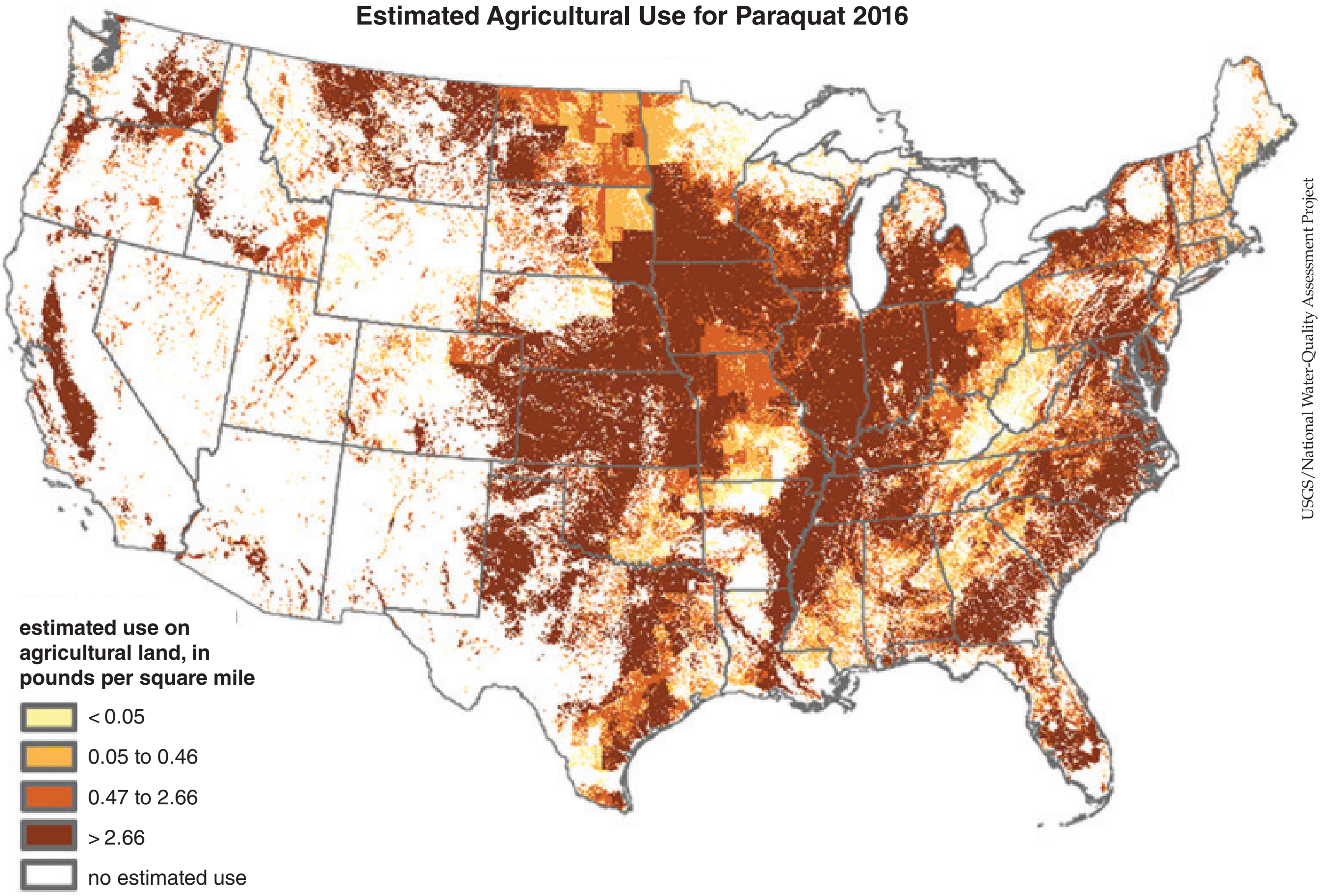
Because of paraquat's link to Parkinson's and its role in the deaths of thousands worldwide, 32 countries, including China, have banned its use (*see the table on page 182*). However, although the United Kingdom prohibits the use of paraquat, a company there continues to export it to the rest of the world. The company, Syngenta, indicated in an EPA filing quoted in Hakim's 2016 *New York Times* report that the evidence of whether paraquat increases the risk of Parkinson's is "fragmentary and insufficient." Farmers in Colombia, Ecuador, Guatemala, India, Indonesia, Japan, Mexico, Panama, Singapore, South Africa, Taiwan, and the United States are all customers.

The United States has not banned all pesticides linked to Parkinson's. The one with perhaps the strongest link to the disease is still in widespread use: paraquat.

Advocacy groups within and outside the Parkinson's community have sought to ban paraquat in the United States. On July 24, 2017, the Unified Parkinson's Advocacy Council, which includes the American Parkinson Disease Association, the Davis Phinney

Robert Dein

Portraits of several Parkinson's patients show the many faces of people with the diagnosis. It affects people from all walks of life.


Estimated Agricultural Use for Paraquat 2016
estimated use on agricultural land, in pounds per square mile
< 0.05
0.05 to 0.46
0.47 to 2.66
> 2.66
no estimated use

USGS/National Water-Quality Assessment Project

Paraquat is a pesticide used on weeds that not even the popular herbicide Roundup (glyphosate) can kill. It is used across the United States, and despite the health concerns associated with it, including Parkinson's, its use continues to increase. This map shows the estimated agricultural use of paraquat in 2016; the high estimate shown here includes usage beyond that reported in surveys.

Foundation, the Michael J. Fox Foundation, and the Parkinson's Foundation, wrote to the EPA, "We write to express our concern with paraquat dichloride, which is shown to increase the risk of Parkinson's disease. We ask the Environmental Protection Agency to deny reregistration of this herbicide based on strong evidence of paraquat's harm to human health."

For pesticides to be sold or distributed in the United States, they have to be registered with the EPA. According to the agency's own rules, registration is contingent on "scientific studies showing that they can be used without posing unreasonable risks to people or the environment."

The EPA itself acknowledges the "high toxicity of paraquat" in its online Pesticide Worker Safety publication, "Paraquat Dichloride: One Sip Can Kill." It includes true stories involving deaths from accidental ingestion of the chemical, including that of an eight-year-old boy who in 2008 drank paraquat that had been put in a Dr. Pepper bottle that he found in the garage. The child died in the hospital 16 days later.

The EPA reviews the safety standards of all herbicides such as paraquat every 15 years. In 2017, they opened paraquat for reconsideration, and it has until October 2022 to make a decision on its future.

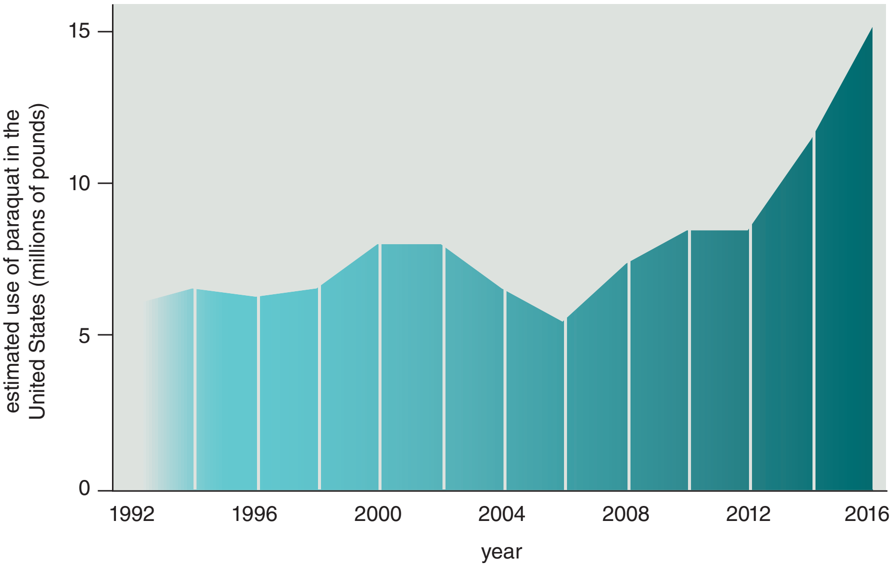
In 2019, in the absence of action by the EPA, the Michael J. Fox Foundation submitted a petition with more than 100,000 signatures to the EPA urging it to ban paraquat. Meanwhile, paraquat use in the United States has doubled over the past decade (*see the figure on the opposite page*). It is now, according to the EPA, "one of the most widely used herbicides registered in the United States." In 2016, more than 5.4 million kilograms of it were sprayed in the United States.

Appropriate equipment can minimize the harmful health effects of pesticides on humans. For example,

list of when select countries banned paraquat

country	year
Sweden	1983
Kuwait	1985
Finland	1986
Germany	1991
Slovenia	1997
Cambodia	2003
Ivory Coast	2004
Syria	2005
United Arab Emirates	2005

Because of paraquat's link to Parkinson's and its role in the deaths of thousands worldwide, 32 countries, including China, have banned its use. Advocacy groups have sought to ban paraquat in the United States. In 2017, the U.S. Environmental Protection Agency opened paraquat for safety review; it has until October 2022 to make a decision about the pesticide's future. (Table adapted from: www.panna.org/sites/default/files/Paraquat%20monograph%20final%202011-1.pdf.)



Paraquat use in the United States has doubled over the past decade. Access to appropriate equipment could help to minimize some health risks. (Figure adapted from R. Dorsey et al., 2020.)

protective gloves can reduce the risk of the disease among farmers who are exposed to some (including paraquat), but not all, pesticides. This kind of equipment and additional protective measures, such as boots, disposable coveralls, and goggles, could decrease the risk of developing Parkinson's disease in the United States and globally.

Cleaning Up

Challenges remain ahead: There is not only much work still to be done to identify what increases one's risk of developing Parkinson's, but also much work to overcome the enormous economic and political pressure that has long favored industry.

In 1964, a decade after demonstrating that smoking causes lung cancer, Sir Austin Bradford Hill gave a lecture to the Royal Society of Medicine that outlined the criteria that an observed association would have to meet to demonstrate causation. The tobacco industry had argued that just because smokers had higher rates of lung cancer was not proof that smoking was the cause. Hill's achievement was to show that population studies could prove that one led to the other. The link between the two had to be strong, it had to be supported by other scientific evidence, and it had to meet other criteria.

Chemical companies have pushed back against the science on Parkinson's. Following the tobacco industry playbook, according to a 2018 investigation by Hakim and Eric Lipton of the *New York Times*, they have lobbied the EPA not to ban certain pesticides by undermining population studies that show the link to various neurological problems, including Parkinson's. But pesticides and other environmental factors tick most, if not all, of Hill's criteria. The evidence includes numerous studies demonstrating a strong link between certain pesticides and Parkinson's, high rates of the disease among those with the greatest exposure, and animal studies that replicate the features of the disease in exposed mice. Based on his criteria, we can conclude that certain pesticides are not merely associated with Parkinson's. They likely cause it.

Not surprisingly, this conclusion is not shared by those who sell pesticides. A 2016 *PLOS ONE* review funded by Syngenta reached a different conclusion: "There may be risk factors associated with rural living, farming, pesticide use, or well-water consumption that are causally related to [Parkinson's disease]," the review says, "but the studies to date have not identified such factors."

The solution to helping end Parkinson's disease is not to expose more people to chemicals that are linked to the disease. The solution is to stop using such chemicals. Other countries with lower incomes and less strict environmental policies have banned paraquat (*see the table on the opposite page*). The United States should do the same.

Many degenerative diseases reflect the environment that our parents and grandparents created. Just as environmental contamination can worsen health and create disease, cleaning up the contamination can have the reverse effect. Enlightened by science, we now can rectify any prior shortcomings for ourselves and our descendants.

Ray Dorsey is the David M. Levy Professor of Neurology at the University of Rochester, where he directs the Center for Health + Technology. Todd Sherer is the chief executive officer of the Michael J. Fox Foundation for Parkinson's Research. Michael S. Okun is the Adelaide Lackner Professor and chair of neurology at the University of Florida. He is the national medical director of the Parkinson's Foundation. Bastiaan R. Bloem is professor of neurology and director of the Centre of Expertise for Parkinson & Movement Disorders at Radboud University Medical Centre in Nijmegen, the Netherlands. In 2004, with Dr. Marten Munneke, he created ParkinsonNet, the largest integrated-care program for Parkinson's patients. This feature is an adaptation from the authors' recent book, Ending Parkinson's Disease. *Website: www.endingPD.org.*

Bibliography

Abbott, R. D., et al. 2016. Midlife milk consumption and substantia nigra neuron density at death. *Neurology* 86:512–519.

Dorsey, E. R., and B. R. Bloem. 2018. The Parkinson pandemic—A call to action. *JAMA Neurology* 75:9–10.

Dorsey, R., T. Sherer, M. S. Okun, and B. R. Bloem. 2020. *Ending Parkinson's Disease*. New York: PublicAffairs.

Saeedi Saravi, S. S., and A. R. Dehpour. 2016. Potential role of organochlorine pesticides in the pathogenesis of neurodevelopmental, neurodegenerative, and neurobehavioral disorders: A review. *Life Sciences* 145:255–264.

Tanner, C. M., et al. 2011. Rotenone, paraquat, and Parkinson's disease. *Environmental Health Perspectives* 119:866–872.

Wong, M. H., A. O. W. Leung, J. K. Y. Chan, and M. P. K. Choi. 2005. A review on the usage of POP pesticides in China, with emphasis on DDT loadings in human milk. *Chemosphere* 60:740–752.

To view this article online, go to

www.amsci.org/magazine/issues/2020/may-june

SCIENTISTS' Nightstand

The Scientists' Nightstand, American Scientist's *books section, offers reviews, review essays, brief excerpts, and more. For additional books coverage, please see our* Science Culture *blog channel, which explores how science intersects with other areas of knowledge, entertainment, and society: americanscientist.org/blogs/science-culture.*

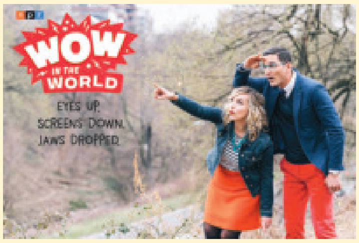
ALSO IN THIS ISSUE

THE ART OF STATISTICS: How to Learn from Data.
By David Spiegelhalter.
page 186

ONLINE

On our *Science Culture* blog:
americanscientist.org/blogs/science-culture

Podcasting Science News to the Next Generation
The wacky characters in "Wow in the World" discuss the latest scientific developments in a tone that kids find engaging—and parents get a kick out of it too.



Robb Hohmann/Tinkercast

Mindy Thomas and Guy Raz host NPR's first podcast for kids, "Wow in the World."

Mathematical Mosaics

OPT ART: From Mathematical Optimization to Visual Design. Robert Bosch. 188 pp. Princeton University Press, 2019. $29.95.

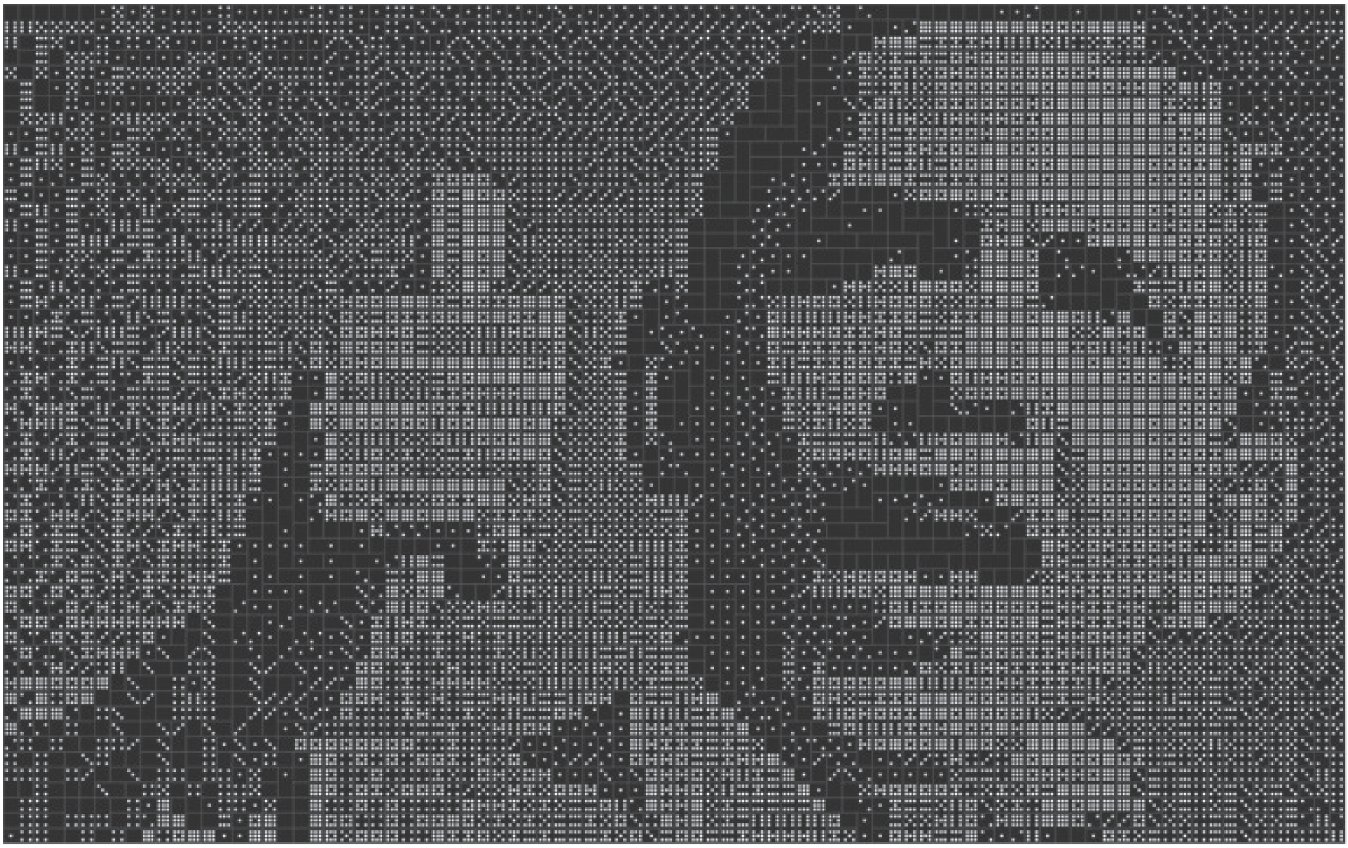
Held at arm's length, the illustration at the top of the facing page is easily recognized as a portrait of the 44th president of the United States. Closer examination reveals that the image is formed from blocks of white dots set against a black background. The dots are the white pips on dominos—specifically, "double nine" dominos, which have from zero to nine dots on each half of a rectangular tile (*see detail below the portrait*). A full set of double-nine dominos contains 55 pieces. The portrait of Barack Obama combines 44 such full sets, for a total of 2,420 tiles, arranged to create light and dark patterns that the eye interprets as an image.

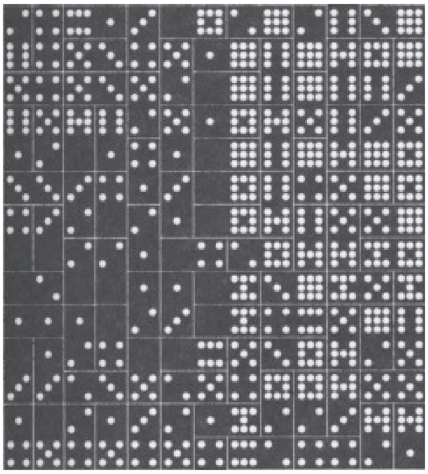
Dominos first became a medium for this type of visual expression 40 years ago in the hands of Ken Knowlton, a computer scientist and artist at Bell Laboratories, whose work appeals to those who like a dash of math and algorithms with their artwork. Robert Bosch, the creator of the Obama portrait, takes this nerdish genre to a higher level of refinement. Starting from a black-and-white photograph or other monochrome image, his goal is not just to produce a good likeness but to find the best possible arrangement of the dominos—the configuration that most closely matches the pattern of shadow and light in the original, according to a mathematical measure. His recent book, *Opt Art: From Mathematical Optimization to Visual Design*, celebrates this idea of optimal or optimized graphic works, along with the computational tools needed to create them.

To build the Obama mosaic, Bosch began with a photograph, using a 55 × 88 grid to divide it into a total of 4,840 square regions. The range of gray levels in the image was compressed to 10 discrete values, labeled from 0 (the darkest) through 9 (the brightest). Then came the tricky part: placing the dominos on pairs of adjacent squares so that the number of pips in each square matched the assigned gray value as closely as possible. As the detail below the mosaic shows, there were many choices to be made, not only in selecting the best tile for each place but also in deciding how it should be oriented. At the end of the process every square needed to be covered, with no gaps or overlaps, and every domino in the 44 sets had to have a home somewhere in the picture.

How can you find the best possible arrangement of 2,420 double-nine dominos? Trying all possible configurations is not a feasible approach. Even working with just a single set of dominos, and ignoring some messy details of geometry and orientation, there are more than 10^{73} ways of placing the 55 tiles. To break through this combinatorial bottleneck, Bosch turned to methods known as *linear optimization*, or *linear programming*. "Linear" signifies that the solution space is bounded by straight lines or flat planes; no curves are allowed.

The problem-solving tools of linear optimization come out of a milieu far from the world of the arts. Historically, they are closely associated with business and economics, logistics, management, and military planning. An airline might use linear programming to match up aircraft, flight segments, and crew members. A chemical plant might use it to adjust its operations to yield the most profitable mix of products. Yet art, too, is an exercise in problem-solving





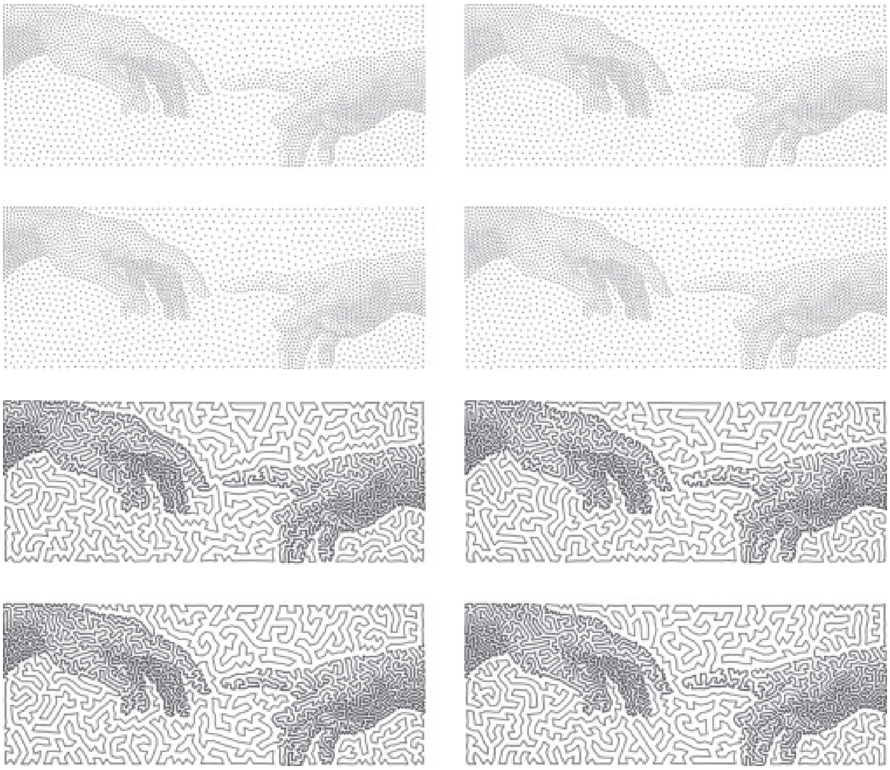
Forty-four sets of dominos have been arranged to create a portrait of the 44th president of the United States in an artwork by Robert Bosch. Levels of brightness and shadow in the portrait are represented by the number of pips on the dominos, ranging from zero to nine on each half of each tile. The pattern shown is the best possible according to a specific measure: For each square cell, square the difference between the number of pips and the desired level of brightness, then take the sum of all these values. The detail at right shows that the choices to be made include not only which tile goes where but also how the tiles are oriented. The version shown is a computer-generated image, but at least two groups of schoolchildren have reproduced this entire tableau using real dominos. From *Opt Art*.

and constraint satisfaction. Furthermore, constraints in the arts can be inspirations rather than obstacles. Bosch cites the example of Georges Seurat's pointillist painting *A Sunday Afternoon on the Island of La Grande Jatte*. "Seurat set himself the task of producing the best possible depiction of what he saw on the riverbank, subject to two highly restrictive, self-imposed constraints: he had to keep his colors separate, and he could only apply paint to the canvas with tiny, precise, dot-like brush strokes." It sounds a little like painting with dominos.

Bosch is a professor of mathematics at Oberlin College, where he teaches optimization (among other subjects). In *Opt Art* he gives a brief explanation of the underlying mathematics, based on a cute question: What can you build with a fixed supply of Lego bricks? He then introduces optimization procedures for some comparatively simple mosaics, in which each tile covers a single square, before turning to the more challenging domino tilings.

The narrative later turns to a quite different kind of data-optimizing artwork: connect-the-dots drawings in which a scene is rendered by a continuous closed path that can be drawn without lifting the pen from the paper. The first step is to create the set of dots to be connected—typically several thousand of them—using a stippling technique in which a higher local density of dots will produce a darker region in the finished drawing. Drawing the path from dot to dot to dot and eventually back to the starting point is where optimization enters the problem. The objective is to find the shortest possible route for such a tour. This is one of the famous hard problems of computer science, known as the traveling salesman problem, which is not believed to have an efficient solution; nevertheless, linear optimization algorithms can find a good tour for problems of the size considered in *Opt Art*. With further work and ingenuity, it is often possible to prove that a tour is not only good but optimal. The illustration on page 186 shows four point sets on top and four corresponding optimal tours beneath them for a detail from Michelangelo's *Creation of Adam*.

I note in passing that the stippled versions of these drawings are actually more appealing to my eye than those with the traced paths. The al-



A connect-the-dots algorithm yields optimized line drawings (*bottom four panels*) for this detail from one of the panels of Michelangelo's Sistine Chapel ceiling painting, *Creation of Adam*. The starting point for each drawing is a stippled version (*top four panels*) of the original image, a version in which the local density of dots encodes the darkness of that region. The optimization step finds the shortest closed path that passes through all the dots. Each of four subtly different stipple patterns yields a noticeably different shortest path. From *Opt Art*.

gorithms for finding a good stipple pattern are also interesting. But in the stippling process there is no criterion for defining optimality; the choice of pattern is made by a more conventional kind of aesthetic judgment, based on what pleases the eye.

Bosch goes on to present a gallery of other graphic fantasies generated by various optimizing procedures, applying them to knots, knight's tours on the chessboard, labyrinths, and tilings that obey additional constraints. One of my favorites is the idea of a "still-life tiling," based on John Horton Conway's Game of Life. The basic elements of the tableau are tiny black or white squares, called cells, arranged in a large grid. What sets the system apart from other tilings is that the cells interact with one another, changing their own color in response to the configuration of the surrounding cells. Bosch sets up patterns that are stable for a while and then slowly disintegrate as a result of these interactions, like a sand painting swept away by the wind.

Opt Art serves as an inviting introduction to a curious corner where art and mathematics intersect. Bosch projects equal enthusiasm for both. The artwork is not just an ornament meant to attract a broader readership, and the math is not just a tool for producing pictures. For Bosch it's clear they both hold deep intrinsic interest, and he communicates this to the reader.

My one major disappointment with the book is that readers who want to experiment with these ideas for themselves may find too little guidance in it to make a successful start. Although Bosch supplies the key mathematical background, the practical details of turning basic principles into working computer programs are rather intimidating. Compounding this problem, Bosch does most of his work with the proprietary software package Gurobi Optimizer, which is available free to those with an academic affiliation but is probably beyond the means of other casual users. Suggesting a few alternatives would have been helpful.

Brian Hayes is a former editor of and columnist for American Scientist. *His most recent book is* Foolproof, and Other Mathematical Meditations *(The MIT Press, 2017).*

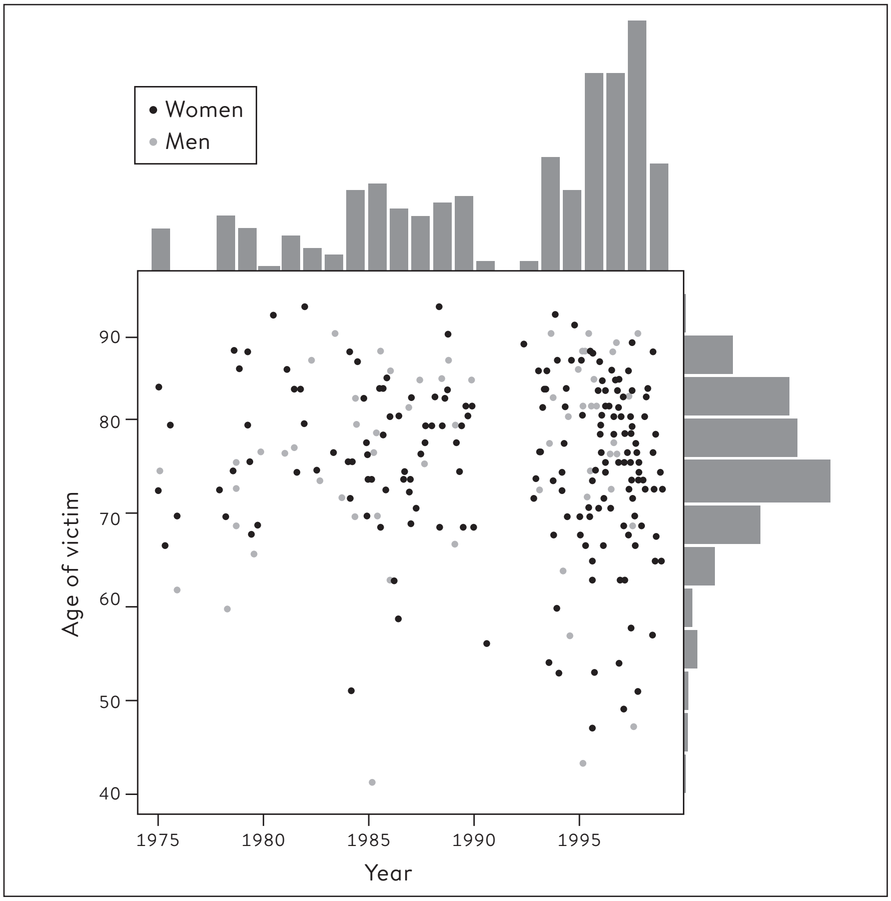
Using Data to Understand the World

THE ART OF STATISTICS: How to Learn from Data. David Spiegelhalter. 426 pp. Basic Books, 2019. $32.

Can statistics be understood without mathematical formulas? Yes, up to a point. *The Art of Statistics: How to Learn from Data*, by David Spiegelhalter, is an introduction to the study of data and statistics for interested readers; it resembles in some ways an introductory textbook but is much less formal. The book emphasizes basic concepts and tools of data representation and leaves out the algebra.

Spiegelhalter has chosen to begin his book not with lessons on probability theory but with exemplary instances of reasoning with data. In an initial example, he discusses the case of an English physician, Harold Shipman, who in 1999 was convicted of murdering 15 of his patients. After the trial, Spiegelhalter and other statisticians were asked to conduct an inquiry into what additional crimes Shipman might have committed. They eventually determined that he had actually murdered at least 215 (mostly elderly) patients over a period of 24 years. Spiegelhalter shows that an exploration of the data regarding the patients who died reveals patterns that lead to insights into Shipman's behavior (*see scatterplot on facing page*). In a subsequent example, Spiegelhalter examines ship records from the *Titanic* to identify the combination of passenger characteristics associated with the highest rates of survival; the most favored passengers were women and children with first- or second-class tickets. In each of these examples, he creates visual displays of data to uncover patterns that are specific to these cases. Because there is no effort to generalize beyond the case at hand, calculations of statistical error are not relevant.

Yet another of Spiegelhalter's cases involves an English hospital's elevated death rates for heart surgery on children. Here the question is whether these bad results are attributable to insufficient experience with this type of surgery at the hospital in question. In this case he would like to generalize, and for a variety of treatments, the candidate explanation of too little specific experience with the surgery is accepted by many. But a statistical calculation of error can scarcely be relevant unless the patients brought to different hospitals can be taken to be comparable. There are good persuasive reasons to think that they are not comparable, and in that case a probability calculation would count for little.



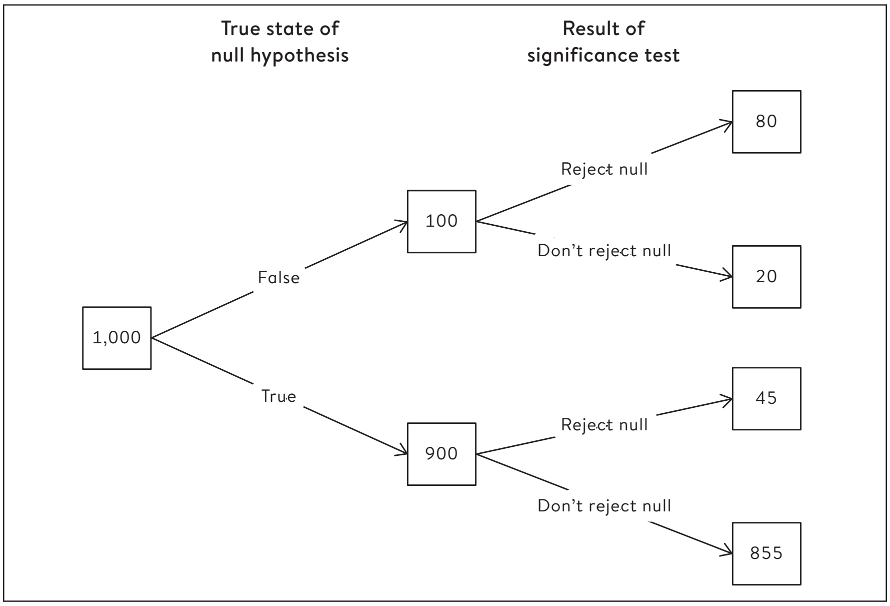
English physician Harold Shipman was convicted in 1999 of murdering 15 of his patients based on evidence obtained from their exhumed bodies. Statisticians who were asked to help determine how many additional crimes he might have committed concluded that he had killed at least 215 of his patients. The ages and years of death of those victims are shown in this scatterplot. The bar charts added to the axes reveal patterns both in the ages of the victims and in the years in which Shipman committed murders. You can see that although initially all of the victims were elderly, in later years he began killing some younger individuals. At about 1992 a gap appears in the top bar chart, indicating that he stopped killing people for a time then. At that same point, he left a joint medical practice, perhaps because he believed he was under suspicion. From *The Art of Statistics.*

Alfred Kinsey, who created a sensation with his American statistics regarding sexual behavior, made no effort to get representative data. Accurate data on sexual behavior are needed for various reasons, including prediction of the spread of sexually transmitted diseases. In the United Kingdom, the National Survey of Sexual Attitudes and Lifestyle (Natsal) was created to obtain such data, and it has been carried out once per decade since 1990. Spiegelhalter discusses some of the results of the 2010 Natsal survey—specifically, the number of lifetime sexual partners reported by people aged 35 to 44 years. The data show obvious anomalies, including higher numbers of reported sexual partners for men than for women and distributions with pronounced peaks at multiples of 10. Statistics as a data science often begins with sometimes tricky problems interpreting data.

Not until page 205, more than halfway through the book, does Spiegelhalter take up the topic of probability theory. Immediately he credits the founding of statistics to a pair of mathematicians, Blaise Pascal and Pierre de Fermat, on the basis of their correspondence in the 1650s on the calculation of odds in games of chance. Singling out combinatorial probability as a unique point of origin can scarcely be reconciled with the perspective of Spiegelhalter's book. Political arithmetic, for instance, which took off later in that century, addressing issues of population, mortality, and wealth, is at least as plausible a candidate. Another is the introduction and systematization of census taking toward the end of the 18th century. The word *statistics* refers to a state science—or science of statecraft—that came to be associated principally with numbers in the 1830s. We might also think of the accumulation and analysis of astronomical and meteorological data. Topics such as these were long central to statistics. With the emergence in about 1930 of a more mathematical version of statistics, this wider field of study tended to fade into the shadows, but it has never disappeared. If anything, it has expanded. Spiegelhalter's book acknowledges and even emphasizes the decisive importance of diverse forms of data work for present-day statistics. It is time now to recognize their central role in statistics across the wide sweep of history.

Leaving aside his Pascal-Fermat creation story, Spiegelhalter's historical perspective on statistics mainly sets off from the English biometricians Francis Galton and Karl Pearson, both of whom treated it as a wide-ranging data science. Pearson, more than Galton, emphasized also the calculation of error as a standard for deciding whether an apparent effect should be accepted as real. Beginning in the late 1910s, another English mathematician, Ronald A. Fisher, reformulated statistics as rules of experimentation, the basis of scientific inference. As Spiegelhalter explains, these methods were bitterly contested almost from the start, especially by Jerzy Neyman and Pearson's son Egon. These rival versions of statistics, Spiegelhalter emphasizes, were never reconciled, and they have intermittently been subjected to severe criticism. Yet a blended or compromise statistics, mainly Fisherian, soon emerged in a range of practical and scientific fields, from agriculture and ecology to psychology, therapeutic medicine, and the social sciences. These versions of statistics, which vary somewhat from field to field, have mostly been treated within their disciplines as gospel.

Spiegelhalter criticizes Fisher's statistics on a number of counts. We would not ordinarily expect an otherwise ge-



Hypothesis testing uses *p*-values and significance testing to evaluate the extent to which data support a given hypothesis (for example, that a drug has a particular effect). The null hypothesis is the default assumption that the postulated effect is absent. This figure shows the expected frequencies of outcomes when 1,000 hypothesis tests of a particular size (5 percent) and power (80 percent) are carried out. (In practice, most studies have less power than that.) One hundred of the tests will indicate that the null hypothesis is false (an effect exists), but our resulting rejection of the null hypothesis will be correct in only 80 (80 percent) of those cases. In the other 900 tests, the null hypothesis will be true (no effect exists), but we will nevertheless incorrectly reject the null hypothesis in 45 (5 percent) of those cases. Therefore, among the 125 cases (80 + 45) in which a "discovery" has ostensibly been made, 45 (36 percent) will be false discoveries. From *The Art of Statistics*.

nial textbook-like introduction to a field to be so critical of prevailing practices. But statistics has long been riven by intense controversy. Although the disagreements persist, they have of late become less virulent. Still, Spiegelhalter and many of his colleagues remain critical of the statistical practices of various scientific fields. Perhaps the worst offenses are associated with pharmaceutical testing and social psychology, both of which have come in for harsh criticism. Statisticians are not alone in perceiving some very serious problems. Some of those problems, Spiegelhalter suggests, reflect fundamental shortcomings of Fisher-style statistics. In particular, Fisher's canonical *p*-values (.05 and .01) do not give us what we want, the probability that a cause is real; rather, they give us something more difficult to interpret, the probability that we would have a deviation of this magnitude without such a cause. Other problems may be understood as abuses to which these methods are vulnerable in the hands of researchers who have a stake in the outcome of the analysis.

Although *The Art of Statistics* is written for an intelligent popular audience rather than for professional statisticians, it provides hints and examples of what the author sees as a better approach to statistics. He is less insistent on controlled experimentation, and more sympathetic to methods that take into account our prior expectations, than are many scientists. He devotes a whole chapter to a defense of Bayesian methods, which indeed are endorsed by many statisticians.

Bayesians hold that statistical analysis should incorporate the reasonable beliefs (*priors*) that we bring to a question. They are willing to pay the price of relying on numbers that may appear to be arbitrary or ungrounded. One extreme example, attributed to John Maynard Keynes, envisages a game of poker with the Archbishop of Canterbury, who in the first hand deals himself a straight flush (Spiegelhalter has "royal flush," but that doesn't accord with the odds he gives and doesn't match other published versions of the anecdote). Did the archbishop cheat? Bayesian probability offers a way to redeem his reputation. The probability of a being dealt a straight flush in a fair game is only 1 in 72,000, making such a deal highly unlikely to happen by chance. But before the poker game began, Spiegelhalter argues, we might have reasonably thought that the archbishop would be extremely unlikely to cheat; we might even have reckoned his prior probability of dishonesty to be as low as 1 in 1,000,000. Comparing that very low, wholly subjective figure to the 1 in 72,000 figure may make us feel more inclined to attribute the straight flush to chance rather than to cheating. In this fashion, a subjective impression of probability can overwhelm an otherwise compelling calculated probability.

Can a postulated probability like the one in this example, which seems so arbitrary, really have a role in sober science? Perhaps. I can imagine, in a discussion among friends, trying out different probability values as a means of groping toward a shared opinion. But such discussion is far removed from the sort of reasoning that has made statistics so central to science, bureaucracy, and medicine. It has mainly been worked out and routinized as the basis for decisions with serious consequences, such as drug licensing, or as a criterion of impersonal science. In those circumstances, invented numbers don't cut it. In pharmaceutical trials, billions of dollars are often at stake. The Archbishop of Canterbury might be able to maintain his disinterestedness in the face of such temptations (who can say?), but profit-driven corporations, on the evidence, are not able to do so. The temptations do not disappear with the redefinition of statistics as the algorithmic analysis of big data.

Sometimes, however, the shortcomings of statistics are attributable to incapacity rather than deceit. Weighty medical decisions regarding painful or dangerous treatments are often based on calculations involving, for example, base rates, false positives, and false negatives—numbers that most people, even very intelligent ones, find it difficult to apply correctly. One key ambition of *The Art of Statistics* is to put forward representations of data that any educated person can understand and deploy appropriately. It is heartening to find that expert statisticians and psychologists are willing to invest time and energy in such efforts.

Theodore M. Porter, a historian of science, is distinguished professor of history at the University of California, Los Angeles. Two of his books from Princeton University Press, The Rise in Statistical Thinking *and* Trust in Numbers*, are being reissued this year with new prefaces. His most recent book is* Genetics in the Madhouse: The Unknown History of Human Heredity *(Princeton University Press, 2018).*

May–June 2020
Volume 29
Number 3

Sigma Xi Today

A NEWSLETTER OF SIGMA XI, THE SCIENTIFIC RESEARCH HONOR SOCIETY

Sigma Xi Reflects on the Past and Plans Ahead

Sigma Xi has released two key documents for the Society: the *Fiscal Year 2019 Annual Report* and the *2020–2025 Strategic Plan*.

The annual report shares stories and data that demonstrate how Sigma Xi is fulfilling its mission to build a strong research community, ensure integrity in science and engineering, and help the public understand the processes and results of research.

For example, last year 560 members volunteered to serve as chapter leaders to achieve Sigma Xi's mission on a local level; 50,000 people came together for research-related chapter events; 3,200 accomplished scientists and engineers were inducted as new members; 600 STEM students received direct support through competitions and grants; and 99,500 readers connected with the Society through *American Scientist*.

The strategic plan is a new course for the future that focuses Sigma Xi's resources and efforts on four main priorities: 1) to advance science, technology, engineering, and math education, 2) to promote scientific leadership and influence, 3) to cultivate a diverse, robust, and inclusive community, and 4) to demonstrate administrative excellence and fiscal responsiveness.

The Society's leadership is calling on members to help carry out this important work. Please visit https://www.sigmaxi.org to learn how to get involved in your local Sigma Xi chapter, a program, or a committee. Both documents are posted in full on the website under the About section.

Sigma Xi Today is managed by Heather Thorstensen and designed by Dena Verdesca.

From the President

Keeping the Public Trust

In the modern world, we are barraged with a wide range of opinions on scientific issues that include the causes of climate change, healthy food choices, and the value of different medicines, including vaccinations. This diversity of opinions, many that question the validity of compelling data, parallels the growth in accessibility of information through social and news media outlets. Separating fact from fiction has also become increasingly difficult for the general population.

Geraldine Richmond

On the positive side, public confidence in the scientific community has increased in recent years. As reported recently by the Pew Research Center, 35 percent of Americans say they have a great deal of confidence in scientists. This value is up 14 percentage points from 2016, and this data is backed by a number of credible studies.

As scientists and engineers, we should all be proud of this positive perception of our efforts. But this is not the time to rest on our laurels. As with many things in our world today, this credibility can easily erode.

We all have a role to play in building and maintaining public confidence in the scientific enterprise. One does not have to look far to find recent reports of scientists and engineers accused of inappropriate professional behavior, many highly respected in their fields. Whether the charges or accusations will be validated is, of course, up to the legal process and the institutions involved. Although these cases are worrisome, they also provide an excellent opportunity for *all* of us to examine what constitutes appropriate professional behavior in our laboratories, our meetings, and our communities.

Many professional societies, including Sigma Xi, are taking these issues more seriously than ever in their development of codes of conduct and guidelines for dismissal of members or fellows. Discussions of the implementation of these guidelines may make some uncomfortable. But such discomfort is important as we seek the best solutions to ensuring confidence in the scientific enterprise. We look forward to your input as Sigma Xi works over the next year to further clarify the expectations and definitions of exemplary behavior of our members in our pursuit of research excellence, discovery, and innovation.

I am proud to be president of an organization that has a 134-year history of electing and honoring members who embody the core values of the Society: excellence, integrity, diversity, scholarship, leadership, and cooperation. Sigma Xi's distinguished history of service to science and society continues today through our chapters, events, and activities.

As Sigma Xi members, we must never forget the important roles we play as mentors, leaders, and ambassadors for science.

Geraldine Richmond

Geraldine Richmond

Wendy Leyden

Artists, astrophysicists, and neuroscientists who collaborated on art exhibits at the Manresa Gallery at St. Ignatius Church in San Francisco discuss their projects.

Sigma Xi Will Showcase Art and Science Collaborations at Its Annual Meeting

Sigma Xi will highlight interdisciplinary collaborations, particularly those that connect art and science, in preparation for its Annual Meeting and Student Research Conference in November, where the theme will be Hacking the Brain: The Intersection of Art and Neuroscience.

From October to December 2019, Sigma Xi was part of *As Above As Below*, a collection of six multimedia and interactive exhibits in San Francisco created by teams of artists, astrophysicists, and neuroscientists. Each exhibit explored the parallels between galactic and neuronal networks. The collection was curated and produced by Esther Mallouh of Keen on Art.

Some of the collaborators sat on a panel discussion, moderated by Sigma Xi Executive Director and CEO Jamie Vernon, for the exhibit opening to discuss their projects and what it was like to work together.

"I think the bottom line of this is that artists and scientists are looking for creative solutions to innovate," said Forest Stearns, the creative innovation consultant and artist in residence founder at Google AI Quantum.

Joel Primack, Sigma Xi immediate past president and a distinguished professor of physics emeritus at the University of California, Santa Cruz, said he came away with a new perspective about his own research.

"In working with Olaf Sporns [of Indiana University Bloomington], who is one of the great experts in how the nervous system is connected, especially the brain, I learned a lot about how to analyze networks, and I hadn't actually gone in that direction before in my own research," Primack said.

While some artists pitched concept ideas to their scientists, artist Anastasia Victor, who designs 3D interfaces and interaction for extended reality, said her team worked together from start to finish.

"It was both a really amazing process and also incredibly challenging, I think for all of us, (a) to determine a shared language, and (b) because we have a certain degree of domain expertise," Victor said. "Being accustomed to having a really comprehensive understanding of a space and then coming into having to negotiate that with other people was a really remarkable part of this process."

Sigma Xi is working with Mallouh to feature some of the artistic collaborations at its meeting in Alexandria.

Sigma Xi Annual Meeting and Student Research Conference

November 5–8, 2020 • Alexandria, Virginia

Conference Tracks

See: Neural and computational mechanisms of vision and their relation to visual arts, data visualization, computer-based vision, and robotic vision

Hear: Computational and experimental methodologies that investigate the brain's response to performing, composing, or listening to music, and the use of sounds in art and communication

Move: How neuroscience and cognitive science inform artificial intelligence and robotics design, and the application of movements such as dance as a therapeutic tool for neurological disorders

Science Communication, Education, and Public Engagement: Communicating science through art; integrating arts and humanities in STEM education, evaluation strategies, and best practices

Research Enterprise and Professional Development: The integration of arts in basic and translational research, cultivating effective interdisciplinary collaborations, leadership training, science policy, publishing, mentorship, and diversity

Research Ethics: Ethical challenges facing the research community, ethics of artificial intelligence and machine learning applications, how neurotechnology may be used to affect human behavior

Grants in Aid of Research Recipient Profile: Ciara Crochet

Grant: $1,000 in Spring 2018

Education level at the time of the grant: Undergraduate student

Project: My experiment involved investigating hormonal predictors of aggression and dominance in coercive, live-bearing fish. Dominance hierarchies ensue in many social organisms as a primary means of reducing prolonged aggression. Social dominance is usually established from aggressive behaviors, or dominant males blocking mating attempts from other, lower-ranking males. In addition to aggressive and mating behaviors, androgen hormones may play important roles in mediating dominance behaviors in many vertebrate species. 11-ketotestosterone (11-KT) and cortisol influence social dominance in many fishes; for example, 11-KT has been found to mediate aggressive behavior as well as male competition, and cortisol has been found to fluctuate during the establishment of dominance hierarchies. Few studies have focused on dominance in animals with dynamic social systems, such as shoaling fishes, where males interact in larger groups for shorter periods of time.

My research provides a potential mechanism to explain the formation of male dominance hierarchies through assessing the potential effects of 11-KT and cortisol on social dominance in competing, coercive males. The results contribute to the field of behavioral endocrinology by providing new information on the role hormones play in aggression and social dominance in vertebrates.

The funds provided multiple enzyme-linked immunosorbent assay (ELISA) kits to detect and quantify the androgen hormone 11-KT, dedicated glassware to avoid contamination, and syringes for both collecting and processing blood.

How the project influenced you as a scientist: This project greatly encouraged me to pursue my passion for research, and it gave me the opportunity to work with other labs. The experience, the opportunity, and the doors the project has opened for me have been invaluable.

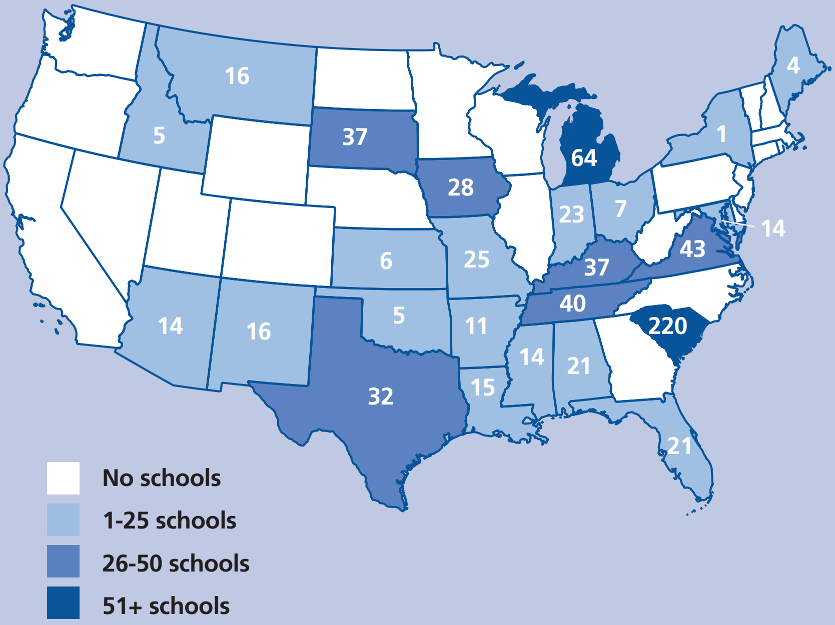
Where are you now? I was inducted into Sigma Xi in 2018, and I have completed my bachelor's degree in behavioral neuroscience. I am pursuing a master's degree in data analytics and completing other research projects on humans and fish. I plan to pursue a PhD in behavioral endocrinology and look forward to continuing to contribute to scientific research.

Ciara Crochet received a grant as an undergraduate student.

Sending *American Scientist* to High Schools

Sigma Xi members and supporters raised $15,864 on Giving Tuesday to send *American Scientist* to 719 high schools throughout 2020. Schools were eligible if they are in one of 25 states where laws or proposals threaten the integrity of science education. The schools were identified through public nominations. Thank you!

Number of High Schools Receiving *American Scientist* by State



Resources That Helped Women in STEM

Sigma Xi asked female members about the resources that have been most helpful to their careers as women in science, technology, engineering, and math (STEM).

Ella A. Kasanga

PhD candidate at the University of North Texas Health Science Center

Seeking advice from mentors is one resource that has been invaluable. My mentors haven't only been senior colleagues but also peers who have provided perspectives that I wouldn't obtain otherwise.

Attending conferences like the Sigma Xi Annual Meeting and Student Research Conference and the Society for Neuroscience (SfN) Annual Meeting has proven very useful. The opportunity to interact with other researchers, exchange ideas, and form collaborations is a gift that shouldn't be looked down upon, especially in the era where collaborative science is gaining popularity. At the SfN meeting, a special luncheon is organized for female scientists, creating a unique avenue to interact with both seasoned scientists and peers. This is an effective way of establishing one's professional support system, which is very important in every field.

I have found the SfN Neuronline platform very useful for finding scientific research, training, and professional development resources, such as virtual conferences.

As a young woman who is gradually building her career in STEM, the experience can be quite overwhelming; however, I strongly believe that with the right resources and support system, a successful STEM career is definitely within reach.

Kelly K. Falkner

Director of the National Science Foundation's Office of Polar Programs

Curiosity and resilience come to mind as qualities that helped me the most to remain motivated and overcome innumerable obstacles to advance my career. I recommend that those who wish to pursue a career in STEM consciously cultivate curiosity for the fun and insights it generates. Surround yourself with people in schools, training programs, societies, and other groups who pursue what makes them wonder, and learn from them. Deliberately exercise curiosity so you don't lose that "muscle" we are all born with.

You are going to need to draw on resilience; while it seems that all human beings long to belong, there will be times when you will feel like you don't. If you feel the confidence slipping, pull out your resume and read it! Let your accomplishments speak to you. If you managed to get this far, you have what it takes to forge on.

Make it a point to pursue activities that fortify your resilience. For me, that included taking regular breaks from STEM matters. The most important resources? Colleagues, friends, and family who can help navigate the challenges as they inevitably emerge. Music, art, athletics, social gatherings, teaching others, volunteering—whatever it takes to keep your perspective healthy and balanced.

Marta Diez-Valcarce

Postdoctoral fellow at the Rollins School of Public Health of Emory University

Personal relationships have been the most helpful resources to my career. Network, meet people, reach out to people you admire. Most of the time people are happy to talk to other scientists who are genuinely interested in what they do. Tell them what you would like to do, what you know, and what you don't know but you would like to learn. Listen to their advice. Magic happens when you listen.

Koji Furukawa

Danielle Wood

Director of the Space Enabled Research Group at the Massachusetts Institute of Technology

When I was an undergraduate student, working in university research laboratories or government internships—such as NASA's internship program—gave me valuable experience. I participated in professional organizations as a volunteer, specifically the International Astronautical Federation and the American Institute for Aeronautics and Astronautics. I earned fellowships from NASA, the National Defense Science and Engineering Graduate Fellowship, and the National Science Foundation's Graduate Research Fellowship Program as a graduate student to support my education.

See more responses at https://www.sigmaxi.org/women-in-stem.

2020

Registration Now Open!

HACKING the BRAIN

The Intersection of Art and Neuroscience

What art and science achieve together that neither could accomplish alone.

RESEARCH CONFERENCE and ART EXHIBIT

www.sigmaxi.org/amsrc20

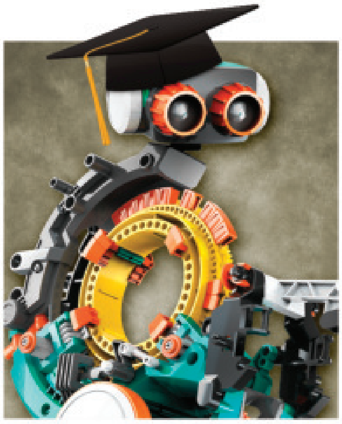
November 5–8

Hilton
Alexandria
Mark Center
Alexandria, VA
USA

Sigma Xi Annual Meeting
& Student Research Conference

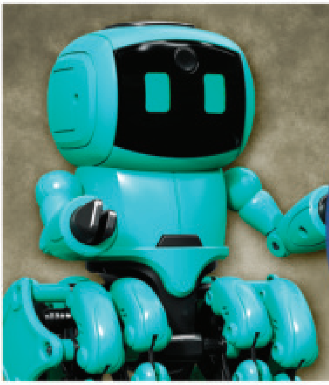
FREE SHIPPING
ON ORDERS $49+
USE CODE: SDAISSUES420

SCIENTIFICS
DIRECT®


MECH-5
"Most Coadable"
#3157009

EVOLUTION
"Biggest Flirt"
#3155876

KIKO.893
"Best Bionics"
#3156304

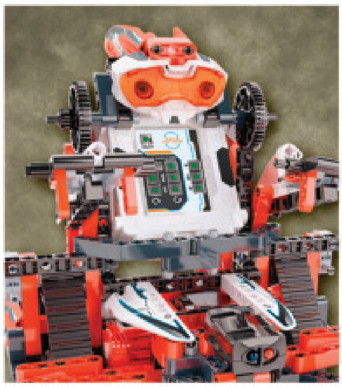

KIKO.962
"Class Cyborg"
#3157161

ROBOTICS UNI.
R
CLASS OF 2020

CYBER TALK
"Most Articulated"
#3156902

TOBBIE II
"Biggest Feedback Sensors"
#3157008

MICRO:BOT
"Life of the Nerd Cave"
#3157095


ROBO MAKER
"Most Transformed"
#3156373

**Discover an Unbeatable Selection
of Robotics at www.ScientificsOnline.com**